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Rapid Prototyping in Design Education: A Comparative Study of Rapid Prototyping and Traditional Model Construction

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RAPID PROTOTYPING IN DESIGN EDUCATION: A COMPARATIVE

STUDY OF RAPID PROTOTYPING AND TRADITIONAL

MODEL CONSTRUCTION

by

Scott D. Greenhalgh

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ABSTRACT

Rapid Prototyping in Design Education: A Comparative Study of Rapid Prototyping and Traditional Model Construction

by

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To evaluate the effectiveness of a rapid prototyping into a curriculum, a study was conducted requiring students to conceive a design and create a model. Students were randomly selected to be given access to the rapid prototype or to create the models by hand. The students' models were evaluated on scale, design, and craftsmanship. Students participated in a survey consisting of perceptions of design feedback and difficulties as well as interests and affective traits. The study utilized qualitative data investigating the instructors' perceptions prior to implementing rapid prototyping into the curriculum and its correlation to observed events.

The study found statistical differences in scale and craftsmanship scores, as well as monetary and time investments with rapid prototyping producing better models at a higher cost with less time invested. The data also suggested rapid prototyping changed the design process as well as shifting affective dispositions within the project.

(184 pages)

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Scott Greenhalgh

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LIST OF ACRONYMS

Organization or definition	Acronym/abbreviation
Engineering and Technology Education	ETE
Interior Design	ID
Interior Design Educator's Council	IDEC
International Technology Education Association	ITEA
Mean	M
Number	#
Number in Sample	N
Rapid Prototyping	RP
Standards for Technological Literacy	STL
Utah State University	USU

CHAPTER I

INTRODUCTION

Creating physical models has traditionally been a part of architecture and architectural education. These models serve several purposes, including providing a demonstrative form of the final project and feedback for revision and improvement within the design process. Models have traditionally been constructed by hand using a variety of materials.

In the 1980s, the manufacturing industry began developing what has evolved into rapid prototype and three-dimensional (3D) printing technology. This technology has provided the ability for designers and engineers to create 3D physical models from 3D computer models. This process involves either the removal of material (machining) or the addition of material (printing). Recently, rapid prototype technology has been incorporated into architectural education (Dimitrov, Schreve, & De Beer, 2006)

Justification

Several programs have incorporated rapid prototyping into their curriculum nationwide (Modeen, 2005) and there are several publications, which are cited later in Table 2, dealing with how one can implement these programs into the curriculum. Most of these publications are case studies where an activity involving rapid prototyping was implemented into an existing curriculum. Many claims have been (and will be) made as to the potential for 3D printing and rapid prototyping to revolutionize or enhance design education. However, no studies we indentified justify the effects as being positive, negative, or comparable when curricula containing rapid prototyping were compared with traditional methods of model construction such as carved models, shaped models out of ceramics, and models constructed from foam core or paper. For many educators, the issue lies in justifying the cost of the technology, which includes not only a start-up cost but also recurring costs in maintenance, materials, and operations. To effectively evaluate if the need and appropriateness for rapid prototyping exist within a program, the costs and benefits of rapid prototyping must be identified and quantified.

Problem Statement

The effects of rapid prototyping are largely unknown. There is no experimental data comparing traditional model construction techniques to rapid prototyping techniques with respect to meeting educational objectives. Likewise, there is no qualitative data comparing rapid prototyping to traditional hand built construction techniques. This information is needed for educators to determine if rapid prototyping is appropriate for their program.

Objectives

The purpose of this study was to compare traditional model building techniques to rapid prototyping in meeting design education objectives. The results are intended to provide educators data and insight into the impacts of implementing rapid prototyping technology into design curricula. The areas of comparison were subdivided into six subproblems and an overall assessment. The first five subproblems address the topic in two parts: first if there is a difference, and secondly, what is nature of the difference. The subproblems and a priori rationale are given below.

Subproblem #1 - Do students receive the same quality and quantity of feedback to improve their designs from each method? If students do not receive the same quality and quantity of design feedback, what is the nature of the difference?

The first of these comparisons investigated the properties involved in the design process. With the replacement of traditional methods of modeling to inspect flow and form for design feedback by 3D computer models (Gibson, Kvan, & Ming, 2002; Kvan & Kolarevic, 2002); the question arises: does the same level of feedback for design improvement exist in both methods? If the level of feedback is not the same, then what is the nature of the differences?

Subproblem #2 - Is the quality of the finished presentation models the same for each method? If the quality of the presentation models is different, what is the nature of the difference?

The second function of a model is demonstration and presentation. Models need to accurately portray the design to other designers, clients, and possibly the general public. This subproblem examines the quality of the presentation model. Are the quality, workmanship, and ability to portray detail comparable within the two methods? If areas of the presentation model differ between the two methods, what is the nature of the difference?

Subproblem #3 - Do students enjoy, appreciate, value, or experience the same frustrations from each method of model construction? If students differ in affective dispositions, what is the nature of the difference?

Another means of comparison was that of appreciation for, value and enjoyment of, and sources and levels of frustration within the project. Educational training can only introduce students to new ideas and methods of approaching problems and designs. The experience the students have with that exercise will often determine the probable usage of tools and methods as a professional after graduation. More positive experiences with exercises in the educational process and their correlating methods will increase the number of tools and methods that may be applied after graduation (Kosslyn & Rosenberg, 2003; Sprenger, 1999). Additionally, there is often a correlation between student enjoyment and performance, and retention of information within the project (Goetz, Frenzel, & Pekrun, 2006; McMillian, 2001) The subproblem will assess if there is a difference between the two methods. If a difference exists, then how great is that difference?

Subproblem #4 - Are the investments of money and time comparable from the students within the project for each method? If the investments are different, what are those differences?

The fourth area of comparison was that of money and time investments into the projects. Methods with less time invested, while retaining quality, will allow employers and educator alike to improve productivity and add depth in other areas. This comparison will address the differences (if any) in the overall time and money invested in the project, as well as the individual components of the project including preliminary design, model construction, design revisions, model revisions, and detailed graphics. A monetary conversion will be given as a per hour rate for time of an intern level employee to complete the project in a professional setting.

Subproblem #5 – Does the availability of technology limit or enhance the design *complexity? If the technology impacts the design capabilities, in which ways, and how great is this effect?*

Design students are expected to explore their creativity. The question was asked, does the availability of technology encourage students to create more complex designs or does it possibly limit the complexity of the design in order to construct the model? Design complexity is considered to be designs which are not easily or clearly represented in two-dimensional drawings (Cheutet et al., 2005). Examples include curves in multiple planes, asymmetrical curves, free-form shapes, and organic shapes.

Subproblem #6 - What are the expectations and potential of rapid prototyping from the perspective of the instructors in the study, and how do expectations contrast to the observed events?

Prior to its adoption, many educators would like to see how rapid prototyping would impact their curriculum. It is difficult to predict the effects of curriculum change without the experience of doing so. This qualitative case study is designed to give the interested educator (stakeholder) the experience of implementing rapid prototyping without the time and financial risk (Stake, 1995; Weiss, 1998).

Overall Assessment

The purpose of this study was to provide data and analysis useful to educators in the construction of curriculum. The individual subproblems were evaluated for curriculum applicability to the outlined program goals for the Interior Design Department at Utah State University (Wickham, 2008) and the professional standards set forth by the National Council for Interior Design Qualifications (NCIDQ, 2008). Accordingly, "technology programs constantly change to reflect society and recent technological advances" (International Technology Education Association [ITEA], 2005) and "technology is a fundamental aspect of human activity" (Dugger & Satchwell, 1996). The need for technological literacy is for all Americans, and is not confined to those studying technology education (Pearson & Young, 2002). The incorporation of rapid prototyping will be evaluated according to the Standards for Technological Literacy (ITEA, 2002).

Assumptions and Limitations

Two major assumptions inherent to the study were: the students participating in the study responded truthfully and accurately to all survey questions; and that the students have equal access to outside help within the scope of the project. In order to meet these assumptions, it was important to get students to take the questionnaire seriously (Suskie, 1996). This was addressed by informing the students that actions may be taken as a result of the findings. Additionally, the truthfulness of the response may be inhibited if they believe their response is not anonymous. A disclosure of the data's usage and how the study may impact the future of the program was made known to the participants when the survey was presented and on the letter of information. The Letter of Information is provided in Appendix F.

The confidentiality of the students was and will be maintained by not releasing student responses on an individual basis, and not releasing student names associated with any data. The students were coded to a responding number; that number was used in all data analysis, and student names and responses were and will not be reported to teachers or departments. This was made clear to the students when the project was presented, on the letter of information, and on the survey.

Equal access to outside help was necessary to balance the data to the participants in the survey. To accommodate for this balance, all students regardless of method assigned were allowed help based on a first come basis. Students using traditional model making methods received additional help including the use of woodworking, soldering and metals manufacturing equipment.

The major limitation to the study is in generalizability to all types of design students and design projects. The experimental population largely female and are interior design students. This may limit the generalizability of the findings to other design students including students using engineering or technology design methods.

Additionally, the findings result from a project with limited opportunity for design revisions. This was due to time constraints within the project. The effects of rapid prototyping on design after completing a presentation model are not addressed in this study.

Definition of Terms

There are several terms used throughout the research project with specific meanings connected to interpretation of the research. These terms are listed in Table 1.

Table 1

Definition of Terms

Terms	Definition
Demonstration models Presentation models Final models	Models used primarily for displaying and demonstrating the finished project.
Design feedback	Information derived from drawings, models, and discussion used for revisions within the iterative design process
Investigative models Preliminary models	Models used primarily for feedback of for to the designer within the creative process
Rapid prototyping Three dimensional printing	A model constructed by automated machinery with information derived from a three dimensional CAD model.
Traditional model construction Hand constructed models Hand built models	A physical model constructed by a person. These models are constructed from a variety of materials including wood, paper, foam, clay and metal. These models can employ a wide variety of construction techniques

CHAPTER II

REVIEW OF LITERATURE

CAD Modeling

With the usage of three dimensional CAD applications, complex models and ideas can be created on the computer. These tools allow designers to experiment with forms without the use of a physical model. A key advantage is the ability of the software is to allow the comparison of concepts without having to create additional models from the beginning (Haik, 2003; Kvan & Kolarevic, 2002).

The use of CAD has changed the design process, as many designers now think through the computer. CAD has been claimed to narrow the gap between representation and building (Ryder, Ion, Green, Harrison, & Wood, 2002). Also known as virtual models, the major drawback to CAD models is that the depth analysis is limited to the representation on the screen and may not include true perspective representation (Eggert, 2005; Ryder et al.). The usage of CAD modeling is an integral precursor of rapid prototype construction.

Rapid Prototyping Defined

Rapid prototyping is a broad term for a variety of manufacturing procedures that stem from information provided from a 3D computer model. Rapid prototyping includes into several methodologies separated by production techniques and processes. Layer manufacturing, stereolithography, selective laser sintering, fuse deposition modelers, 3D printing, and computer numerical control (CNC) machining are the most common processes. These methods fall into two subcategories; additive and subtractive processes. The technical differences between these methods will not be discussed as they do not apply to the scope or intent of the study. It should be noted that the usage of the term “rapid” may be a misrepresentation as the process can take hours to days of processing time (De Beer, Barnard, & Booysen, 2004).

Subtractive Manufacturing

CNC machining is a subtractive method of construction as material is removed from a block of material. CNC machining is closely related to manufacturing, and depending on the machine and material, may require placement into a manufacturing setting, as opposed to the office setting in most design and architectural firms. Because of this and the high cost of CNC machinery, architects and designers typically avoid this method while professionals specializing in model construction often employ this technique (Kvan & Kolarevic, 2002).

Additive Manufacturing

Layer manufacturing is a broad term where the model is constructed using additive techniques in a graduated layer system along the vertical relief. These techniques are most common in architectural and design schools and offices that construct models and will be the focus of this study. One of these techniques borrows from ink jet printer technology. This technique applies a thin layer of powder like substance and a liquid binder or laser process and is “printed” onto the desired area. After multiple layers, the object is defined and excess powder is removed. Another common method is a process where molten material is printed as a bead one layer at a time. This molten material, typically a plastic, solidifies into the final project (Dimitrov et al., 2006).

Usage of Rapid Prototype Technology in Architecture and Design

CNC Machining

Currently, the major usage of rapid prototype technology in architecture and design is the use of CNC and laser process by dedicated model makers. This process requires the product to be redrafted into sections according to capabilities of the machinery. These sections must then be assembled for the final model. This process has lower material cost than layer manufacturing, but requires more time to construct. The time comparison is dependent upon the complexity of the model. Advantages include the ability to use a variety of materials including plastics, wax, wood, and metals (Ryder et al., 2002).

Layer Manufacturing

Although considered a better fit for architectural firms due to their office friendly nature, layer manufacturing production is slower to be adopted in architecture than in other fields. This is partially attributed to architecture not being strongly linked with engineering and manufacturing (Giannatsis, Dedoussis, & Karalekas, 2002). The use of 3D CAD models can convert information easily into layer manufacturing files. One strength of layer manufacturing is the ability to easily duplicate designs as CAD software allows for copying and mirroring of existing components (Modeen, 2005) Additional advantages include the ability to construct complex forms as easily as rectilinear shapes (Gibson et al., 2002). Recent developments such as color-rapid prototyping, speed and efficiency of processing, and lower cost may make rapid prototyping more appealing to architects and designers in the future. For this study, a layer manufacturing process was be used on a Dimension 3D printer (model SST 1200, Stratasys Inc., Eden Prairie, MN). Although this particular method was used for this project, it has been noted that no single system or method has become dominant within either the manufacturing or the architectural user base (Wai, 2001).

There are several disadvantages to layer manufacturing. The first disadvantage is that of machinery cost. This is an additional capital expense that may be considered unnecessary, and may explain the slow response of design and architectural firms adopting the technology. A second disadvantage is that of limited printing size. This limits the scale of the project and assembly be required for larger or more complex models (Ryder et al., 2002). In a comparison, many common layer manufacturing machines have a maximum print area of approximately than 8” by 12” by 8” deep (Modeen, 2005). Additionally, layer manufacturing limits the materials available for modeling (Bohn, 1997).

Usage of Rapid Prototyping Technology in Education

There are several publications addressing the implementation and educational benefits of rapid prototyping technology into curriculum. Theses publications have been found through searches of ERIC (Educational Resource Information Center), Web of Science, and Digital Dissertations. Additional citations were noted from articles found in this search. This search has yielded only 10 publications addressing the usage of Rapid Prototyping in architecture or design and education. The majority of the articles are a case study discussing how a curriculum involving rapid prototyping was created and implemented. Table 2 summarizes the major claims of the publications, whether the article discusses implementation and usage strategies, specifically states whether Rapid Prototyping is beneficial in education, and any studies or statistics cited or supporting that claim.

These articles show a lack of comparison between rapid prototyping and the traditional methods they replaced. There are no cited experiments or quasiexperiments given to assert any claim as to a benefit of one technique over another. Likewise, no text is an example of qualitative research as defined Silverman (2005). None of the texts address the research question: how does rapid prototyping compare to traditional model building techniques in meeting design education objectives?

Model Usage in Design Education

Model construction is considered a fundamental tool of design and has been for many centuries (Gibson et al., 2002). Traditional techniques in model construction involve a variety of materials including wood, paper, foam, and clay. Models can serve as the bridge between ideas and the physical world. Complex ideas are often more easily communicated in models (Frampton & Kolbowski, 1981). The usage of these models is divided into two main purposes: investigation and demonstration (Alley, 1961).

Investigative Models

Investigative models are primarily for feedback of form to the designer and architect and are an integral part of the creative process (Starkey, 2006). These models

Table 2

Summary of Related Articles in Rapid Prototyping and Architectural Education

Article title	Major claims	Discusses implementation and usage strategies	Is rapid prototyping beneficial in education?	Citations and or studies/ statistics given to that claim
Integrating rapid prototyping into engineering curriculum (Bohn, 1997)	A senior level course in rapid prototyping is possible and has been successful	Yes	Yes "obvious and well documented"	No data comparison. An implementation and success study.
Advances in three-dimensional printing: state of the art and future perspectives (Dimitrov et al., 2006)	Rapid prototyping has improved and will continue to improve in many fields	Yes	Not discussed	No
Rapid Prototyping for architectural models (Gibson et al., 2002)	"Some examples have been shown and… RP modeling can be particularly useful"	Yes	Yes	No data comparison. An implementation and success study.
Architecture scale modeling using stereolithography (Giannatsis, Dedoussis, Karalekas, 2002)	Investigated the applicability and effectiveness of rapid prototyping to scale modeling for architectural design.	Yes	Not discussed	Compares additive methods with milling techniques on two large-scale projects.
Rapid design and manufacture tools in architecture (Ryder et al., 2002)	There remains a great deal of uncertainty concerning the applicability and role of layer manufacturing to a number of applications including architectural design.	Yes	Not discussed	Cost comparisons between layer manufacturing and traditional model construction for professionals.
Three dimensional plotting as a visualization aid for architecture use (De Beer et al., 2004)	"RP would not be an economical solution in order to produce all the architectural models"	Yes	Not discussed	A cost analysis is given comparing layer manufacturing to CNC methods.

(*table continues*)

Article title	Major claims	Discusses implementation and usage strategies	Is rapid prototyping beneficial in education?	Citations and or studies/ statistics given to that claim
Translations- fabricating space (Iwamoto, 2004)	Study showcases several student projects created using various RP techniques.	No	Not discussed	No
RP in art and conceptual design (Wai, 2001)	“the obstacle to adopting RP to art and conceptual design is rooted in common characteristics of commercial RP systems that are incompatible with the creative process”	Yes	Not discussed	No
Classroom evaluation of a rapid prototyping system (Flowers, 2002)	“The purpose of this article is to share the authors’ experience with the JP System 5 (a particular brand), analyze its strengths and limitations and recommend how to use it effectively”	Yes	Not discussed	No data comparison. An implementation and success study.
Rapid prototyping in technology education (Tennyson & Krueger 2001)	“Rapid prototyping, while costly, can afford students a unique opportunity to bring their ideas to reality”	Yes	Yes (“it has revolutionized the teaching of technological design at one university”)	No data comparison. An implementation and success study.

are used to define the basic design, spatial relations, proportion, and flow within the project. Architects and designers have been using this process since the Renaissance and it has been suggested that the word "model" is derived from an Italian source that refers to something incorporating a design idea (Janke, 1968; Starkey).

The construction of the investigative model is often minimal in detail with the focus on the visual concept of form and relative size. Models themselves can be a medium to think through and draw ideas from spaces. "Spatial thinking" as constructed in the modeling stages will result in a different form than the plan derived from floor plans (Kelley, 2001).

By disaggregating a project into components, the very process of model construction can be viewed as a means to analyze design concepts on complex problem, which may as a whole seem insurmountable (Janke, 1968). As 3D computer modeling and rapid prototyping replace traditional techniques; the question remains "is the feedback received by the designer is comparable between the methods?"

Demonstrative Models

Also known as presentation models, demonstrative models serve the purpose displaying finished project ideas. These models are usually of higher quality and are used to display the final product. Presentation models convey information as to the appearance, use, and structure in ways graphic models cannot (Frampton et al., 1981). The models allow architects and designers to present ideas and complex building schemes that are difficult to interpret in two-dimensional drawings. This form of communication is highly valued when the presentation involves those who are not trained in the profession of design. Dennis Boyle, the veteran studio head of IDEO, a leading design firm, stated, “never go to a meeting without a prototype” (Kelley, 2001).

Disadvantages and Limitations of Models in Education

Several disadvantages exist to the usage of models. The first is that students do not always see the value of the exercise. The connections of a communication tool and design feedback are not always understood by students (Alley, 1961). Another disadvantage is that too much is expected from the model. The model is only a visual representation and does not guarantee the appearance of the final product. Exact scale of details and perspective views from the full-scale equivalent are not represented in the models. Additionally, students are reluctant to revise, review and improve their models once they are created because of the time required in model construction (Krathwohl, Benjamin, & Masia, 2001; Sprenger, 1999). For rapid prototyping, this may include a reluctance to revisit a CAD model as needed, or to reprint a model due to the cost involved.

Affective Domain

Several factors in an educational program are not exhibited in typical testing measures of knowledge and skill. One strong factor includes the affective domain of learning which is defined as “the traits and dispositions different from knowledge, reasoning and skills” (McMillian, 2001). This includes the emotions, feelings, values, self-concepts, and citizenship of students. The affective domain and learning are strongly connected (Kosslyn & Rosenberg, 2003; Ormrod, 1999). Many common measures of the affective domain center on attitude traits. Attitudes do not refer to a behavior, but reflect the internal reaction or state towards an object, situation, person, or environment (Krathwohl et al., 2001). Some of the most powerful uses of interest assessment are in the areas of values and abilities. This assessment is most affective in career exploration and development (Hansen, 1995). Students place a value upon model construction based upon their experience (McMillian). If the experience is viewed as valuable, then the likeliness of model construction being organized and characterized as a design tool or means of communication increases. Inversely, frustration is likely to yield model construction as a process to be avoided in future projects (McMillian).

Measuring for affective traits requires three key assumptions (Suskie, 1996). These include:

1. Students will take the assessment seriously to provide accurate results
2. Students need to feel their responses are anonymous; and
3. Student responses do not vary according to momentary or temporary moods.

There are three common methods for assessing affective traits: teacher observation, student self report, and peer ratings (Gall, Gall, & Borg, 2003). This study focused on student self-reporting through a survey. Observations were recorded and reported, but only show a small window of the project as much of the project was completed by students outside of class hours. The usage of peer ratings were inconducive to the research project. One method for achieving success is demonstrating how the survey is relevant to the students and that actions may be taken as a result of the findings (Stangor, 2004). Selected response formats are a method which allows students to select their agreement or disagreement to a statement. One common format is the use of a Likert scale (McMillian, 2001). This scale allows for respondents to select from a list of responses their level of agreement or disagreement. This response can then be quantified according to these levels.

Money and Time Comparison

All technological activities require resources. Resources consist of: tools and machines, materials, information, energy, capitol, time, and people (ITEA, 2005). This project will consider two of these resources. The first factor to be analyzed is that of the time required to construct the model. Methods with less time associated allow employers and educator alike to achieve greater levels of production and allows for resources to be assigned elsewhere. Table 3 shows the median salary for full time designers, architects, and drafters as reported to the United States Bureau of the Census (2005). Full-time salaries will be divided by 2,000 to derive an hourly equivalent. This value assumes 50 weeks per year and 40 hours of work per week. Surveys by the College Placement Council and Edison Electric Institute estimate internship pay rates to be between 50% and 75% of starting salaries for graduates (Dominion, 2007). The table uses a conservative 50% rate to calculate hourly intern pay rate.

Additionally, a simple cost comparison of materials is of concern for both employer and educator as both are controlled by available funds. This analysis will assist in understanding the time-money balance in classroom projects comparable to a professional scenario.

Table 3

Salary and Expected Intern Pay Rate

Job title	Median salary (full time)	Hourly rate	Expected intern pay
Architect	$51,081	$25.54	$12.77
Designer	$35,760	$17.88	$8.94
Drafter	$35,583	$17.79	$8.90
Average	$40,808	$20.40	$10.20

Survey Usage as a Data Collection Tool

A survey is a series of self-reported measures and is the most widely used method of collecting descriptive information about a population (Gall et al., 2003; Leedy & Jeanne, 2005). It is essential to the research that the survey is valid and reliable. In survey analysis, validity addresses the appropriateness, meaningfulness, and usefulness of the data collection instrument (McMillian, 2001; Stangor, 2004). Validity is often divided into two major types: internal and external validity (Leedy & Jeanne, Rossi, Freeman, & Lipsey, 1999; Stangor, 2004; Weiss, 1998).

Internal Validity

Internal validity addresses how well the instrument measures what it is intended to measure and is often further defined into four common types of internal validity (Gall et al., 2003; Leedy & Jeanne, 2005).

1. Face validity – the extent to which a measure appears to measure what is claimed. This measurement is subjective and alone does not guarantee validity. The study will approach face validity issues through an evaluatory panel (thesis committee).

2. Content validity – the extent to which a measure addresses the complete content area or domain as intended. This study addresses content validity through identifying all known possible factors. The exploratory nature of the qualitative portions of the study is designed to address the need for content validity.

3. Criterion validity – the extent to which the results for the assessment instrument correlate with another similar or identical measure. This study compares the two groups of rapid prototyping and hand constructed techniques on the same instruments with the same scales, measures and evaluators.

4. Construct validity – the extent to which an instrument measures a characteristic that cannot be directly observed. This includes creativity, motivation, values and emotions. This area of validity applies to the affective dispositions section of the survey. The use of four triangulating affective dispositions was designed to identify any construct validity issues when identifying similar affective traits.

External Validity

External Validity addresses the extent to which a study can be generalized to a larger population. Factors addressed in external validity include the representative nature of the sample population to the larger population, and the congruency of the experiment to real-world scenarios. The external validity can be enhanced by larger, representative, and random samples (Carspecken, 1996; Denzin & Yvonna, 1998) and the similarity of the study to other cases (Suskie, 1996). An educator who is knowledgeable about both cases would have the strongest ability to evaluate the transferability of findings and conclusions to another case. A description of the case, program, and activity are provided to assist other educators with the background necessary to evaluate if the findings should apply to their case (Stake, 1995).

Reliability

Reliability is the ability of an instrument to yield consistent results. Reliability has been subdivided into four key types of reliability (Wiggins & Jay, 2005).

1. Interrater reliability – the ability of two or more evaluators to yield consistent results. To address the interrater reliability, independent sample *t* tests were conducted between evaluators' scores for the same student.

2. Internal constancy reliability – the extent to which all item within an instrument yield similar results. Evaluators did not evaluate students in the same order within this study. Any evaluator drift over time would be identifiable in the independent sample *t* tests.

3. Equivalent forms reliability – the extent to which multiple forms of the same instrument yield similar results. Only one form of measurement was used in this study.

4. Test-retest reliability – the extent to which the same instrument will yield similar results on different occasions. There were no time series or multiple tests given in this study.

Survey Relevance

The most important factor in a survey is relevance. A validated survey that is not relevant is invalid to the study (Leedy & Jeanne, 2005; Stangor, 2004). For this reason, many surveys are constructed to fit the relevance and need of the study. This study utilized a survey constructed to fit the needs of the study. This was done according to techniques outlined by Fowler (2002) and Suskie (1996).

Evaluating Design

Evaluating design is a highly subjective measure. What one person may consider good design, another may not. To addresses these personal differences, two methods have been employed to evaluate design. The first was utilizing a jury method to collectively judge designs. This method utilized several experts in the field who all individually evaluated the design. The judges' scores were averaged, giving a score reflective of the overall impression of the judges. The strength of this method lies in the judges being trained how to judge the designs, and the second relies on the judges having a level of expertise (Kliment, 1995; McLaren, 1997). This method is utilized by design contests (Johnson, Morlino, & Shaub, 2005; Kim-Jamet, 2007) and is similar to sporting events such as diving and gymnastics. The second method used in the assessing of design is utilizing a rubric scoring guideline.

Rubric Usage as a Data Collection Tool

A rubric is a combination of a rating scale (fixed measurements) and a scoring guideline (descriptions) designed to evaluate degrees of quality, proficiency, or understanding (McMillian, 2001). The intention of a rubric is to bring a level of objectivity into an otherwise subjective judgment. Rubrics need to address the factors of content validity as stated above. A valid rubric will incorporate the all the criterion necessary to accurately evaluate the design project. Not only must all necessary criterion be present, scoring values must be present in the correct ratio to reflect an accurate judgment (Leedy & Jeanne, 2005; Moore & McCabe, 2006; Oehlert, 2000; Rossi et al., 1999; Stangor, 2004).

Hypothesis Testing, Errors, and Statistical Power

The research hypothesis is typically tested in the form of the null-hypothesis. This study will test against the null hypothesis for the first five subproblems. The null hypothesis states that there is no difference between factors, and all observed differences are due to chance. The null hypothesis is rejected (acknowledgement of a difference between factors) when the statistical probability of a measurement (*p*-value) is lower than the established significance level (alpha). The significance level is typically set to $p < .05$, but is not required to be (Moore & McCabe, 2006; Stangor, 2004).

There are two major statistical errors possible within any analysis. Theses have been titled type I and type II errors. A type I error is when the null hypothesis is rejected when the difference between factors exists only due to chance. When the significance level is set to $p < .05$; there is a 5% chance of making a type I error (Gall et al., 2003; Gravetter & Wallnau, 2005; Oehlert, 2000; Stangor, 2004). A type II error is the acceptance of the null hypothesis when a difference does exist. The occurrence of a type II error is dependent on the statistical power of the study. The power is equal to one minus the probability of a type II error. Therefore, the greater the statistical power, the lower the probability of a type II error. Statistical power can be raised most easily by a larger sample size, or relaxing the desired effect size (Stangor). Table 4 is given of the required participants to avoid a type II error per effect size with a power of .80 and alpha set to .05 (McMillian, 2001; Rossi et al., 1999; Stangor; Weiss, 1998).

Table 4

Participants Required Per Design Method

	Estimated *ES*		
	Small	Medium	Large
Correlation coefficient	783	85	28
One-way (between participants) ANOVA			
2 groups	786	128	52
3 groups	966	156	63
6 groups	1,290	210	84
Factorial (between groups) ANOVA			
2x2	788	132	56
2x3	972	162	66
3x3	1,206	198	90
2x2x2	792	136	64
Contingency table (chi-square)			
1 *df*	785	87	31
2 *df*	964	107	39
3 *df*	1,090	121	44
4 *df*	1,194	133	48
Multiple regression			
2 IV's	481	67	30
3 IV's	547	76	34

Note. Power = .80 and Alpha = .05 (Cohen. 2008).

This study utilized an alpha level of .05. With this study, it is shown that the smaller sample size of the study, only effects that are considered "large" will be detectable in the study at the given alpha level. This then open the possibility for a high type II error rate. To identify possible type II errors all statistical tests with an alpha level less than .15 are noted in the text as possible relationships, which may be identified as statistically significant in a test with greater power. These areas are suggested for further investigation in subsequent studies.

CHAPTER III

METHODOLOGY

Project Description

To collect data for the comparison, a study of two sections of an interior design class was compared. The classes consisted of an interior design course at Utah State University titled “Interior Space Planning and Human Dimensions.” The classes were composed of interior design majors with a total enrollment of 46 students. Each section was taught by a different instructor. The study used a mixed-methods approach (Carspecken, 1996; Creswell, 2007; Stake, 1995).

Class Project Description

A major assignment within the course was the design and marketing of an original chair. As part of this assignment, a physical scale model was required. The model was expected to be of high quality and for the appropriate marketing of the chair. The quality of the model design, scale and craftsmanship were the areas of grading consideration. The models was analyzed according to scale, design and craftsmanship as outlined in the grading rubric provided as Appendix B. There were no limits for material selection as long as the material reflects the visual intentions. The assignment took three weeks of the course’s curriculum. The first week was focused on design, the second week was focused on model construction, and the final week was focused on marketing of the chair. This was not the students’ first exposure to model construction. Many have been exposed to modeling in art classes, and all students participated in a modeling project earlier in the year. See Appendix C for an outline of the assignment.

Selection of Students

Students were presented with the project and the assignment to create preliminary sketches of the model they propose to build. All students were given an hour-long introduction to rapid prototyping. This included an introduction to the CAD processes necessary to rapid prototyping and printing of a small project. The concept and demonstration of rapid prototyping was presented to the class before students have conceived their design. Students were presented with the option to participate in the study and made aware of the following.

1. Students will be randomly assigned to either a control or experimental group. Participation allows the student the opportunity to use the rapid prototype machine based on chance randomization.

2. Participation requires students to fund their projects.

3. Participation is voluntary and students may wish to withdraw at any time.

All students were invited to participate in the study. Students wishing to participate were given an identification number. Each student was assigned to a method of model construction using their identification number. This selection was done using a random number generator. Each student had equal probability for selection (50%) within each class section. Twenty-eight students chose to participate in the study with four-teen being assigned to each group.

Description of Project Events

Students who were randomly chosen to build models using the rapid prototyping machine then proceeded to create 3D CAD models. Students creating hand built models proceeded to design their models in the method that suited them best. Students in the rapid prototyping group completed their designs using AutoCAD software (Version 2008, Autodesk, Inc., San Rafael, California) and were ready to print as early as two days after having a rough outline of their design. After this rough outline was conceived, the students had 10 days to complete the final model. A steady stream of students began to start printing 8 days before the model was due and all models except two were finished printing 2 days before being due. One of the unprinted models was due to file conversion difficulties, and the student redrew the model and was printed the following day. The other was attributed to procrastination. It was observed that the process ran smoothly with one model failing to print correctly. This model was reevaluated according to the printer setup and was successfully reprinted.

The researcher attended all classes to field questions as to the rapid prototyping process and fielded questions to hand construction techniques. The researcher directed hand construction students to woodworking and metalworking laboratories to receive help as needed, and directed rapid prototyping students to necessary printing procedures. This availability of help to all students was done to address validity concerns of additional resources and help being provided to one group of students. The researcher has a woodworking and manufacturing background, and access to such equipment in the Utah State University Department of Engineering and Technology Education. Eight students using hand construction methods used the equipment of the Engineering and

Technology Education Department. This included a table saw, band saw, scroll saw, disc sander, oscillating spindle sander, soldering equipment, and precision sheet metal bending equipment. All students were helped on a first-come, first-serve basis regardless of construction method used.

The students were asked to record their daily time and cost sheets at every class. Following the study, students were asked to take the survey and three instructors from the interior design department scored all projects according to the scoring rubric. These four quantitative measures were designed to address six subproblems. The role of the measures in addressing these subproblems and individual items are described below. The four quantitative measures are presented as Appendices A, B, D, and E. Additionally, qualitative measures of interviews, public records, and observations and field notes were used to address questions not easily answered by quantitative measures (Gall et al., 2003). These measures are presented in Appendices C, G, and H.

Subproblem #1. Do students receive the same quality and quantity of feedback to improve their designs from each method? If students do not receive the same quality and quantity of design feedback, what is the nature of the difference?

The students were assessed on the quality of design feedback according to the method of model construction they used. The method of receiving data was given as a self-reporting survey at the completion of the project. The surveys addressed questions of the amount and the effectiveness of the feedback they receive from model and various design tools. These questions allowed students to respond to how much feedback they received from individual activities within the project. All questions were posed as and agreement to a statement given on a four-level Likert scale (Gravetter & Wallnau, 2005;

Stangor, 2004; Wiggins, 2005) with a fifth level being for having not used a particular method. Table 5 shows the questions addressing subproblem #1. Appendix A includes the questions in the order and format as found on the survey.

Table 5

Questions Asked in the Survey Addressing Subproblem #1

Question	Strongly agree	Agree	Disagree	Strongly disagree	Did not use
1. The following tools have influenced my design greatly:					
2. The following were effective in sharing information and ideas with others:					
Preliminary sketches					
Preliminary models					
Final models					
2D CAD drawings					
3D CAD models					
2D hand drawings					
3D hand drawings					
3. The following people have influenced my design greatly:					
Instructor					
Other instructors in interior design					
Students in class					
Other students in interior design					
Other students NOT in interior design					
Family					
Other					
4. Overall I feel the quality of my design has improved throughout the project:					

Analysis of subproblem #1. The first subproblem was analyzed by sources of feedback with those sources being intrapersonal and interpersonal feedback. The responses to each question was coded into numerical data with "strongly agree" being replaced by a value of one, continuing by whole numbers in order of agreement up to "strongly disagree" being replaced by a value of four. The response "did not use" was analyzed separately as a percentage difference between groups. Each question was analyzed using a cross-tabulation separated by construction technique used. The chi-square test for independency was utilized because of the small sample size, usage of ordinal data, and the distribution of the variables is strongly nonnormal (Cohen, 2008).

Subproblem #2. Is the quality of the finished presentation models the same for each method? If the quality of the presentation models is different, what is the nature of the difference?

The students were assessed according to the quality of the presentation model they create. Three instructors (Steven Mansfield M. Arch.; Deanne Olsen M.S. ID; Susan Tibbitts M.S. ID) from the Utah State University Interior Design program performed the evaluation. The model was assessed using a rubric with numeric equivalents given to specific areas of quality. Areas that were assessed included: overall workmanship, scale representation, design, appearance as to selected material, and reflection of model to projected product. Assumptions taken into the method of data collection are centered on evaluator bias. Three evaluators were used to minimize bias, checked for interrater reliability, and instances of a possible "halo effect" (McMillian, 2001). An analytic rubric was used with examples of score values to minimize subjectivity (Gall et al., 2003). See Appendix B for the rubric used.

Analysis of subproblem #2. Subproblem #2 was analyzed according to an independent sample *t* test. The average of the scores of all the evaluators was used in the *t* test. The three individual factors of scale, design, and craftsmanship, as well as the total of all three factors were analyzed by the model construction technique. The mean, standard deviation, standard error of the mean, and the probability values were all reported in analyzing the second subproblem.

Subproblem #3. Do students enjoy, appreciate, value, or experience the same frustrations from each method of model construction? If students differ in affective dispositions, what is the nature of the difference?

Students were assessed according to their perceptions, values, enjoyment, and frustrations within the project. The method of receiving data was by a self-reporting survey. The survey was given using the affective measures of enjoyment, value, appreciation, and frustration (McMillian, 2001) with the same Likert scale as described in subproblem #1. All affective domain questions were formatted similarly to questions in subproblem #1 with a statement given, and a level of agreement was selected for each ranging from strongly disagree to strongly agree. Each question required a level of agreement to that statement for each activity in the design project. Table 6 shows the questions addressing subproblem #3. Appendix A includes the questions in the order and format as found on the survey.

Analysis of subproblem #3. The areas of enjoyment, frustration, and value were evaluated to identify correlations between the two assigned methods of model construction. This was performed using a chi-square test in the same manner as questions for subproblem #1. The two open ended questions asking the most positive and negative

Table 6

Questions Asked in the Survey Addressing Subproblem #3

Question	Strongly agree	Agree	Disagree	Strongly disagree	Did not use
1. I enjoy doing the following:					
2. I was frustrated doing the following:					
3. If I were faced with a similar design project as a professional after graduation, I would likely create a:					
4. As a student learning about design, I find the following to be valuable:					
Preliminary sketches					
Preliminary models					
Final models					
2D CAD drawings					
3D CAD models					
2D hand drawings					
3D hand drawings					
The following were open-ended questions					
5. What was the most positive part of creating a model?					
6. What was the most negative part of creating a model?					

aspects of creating the model were coded for similar responses and frequency counts of the similar responses. The similar responses were reported as written and described by the students (Carspecken, 1996; Silverman, 2005).

Subproblem #4. Are the investments of money and time comparable from the students within the project for each method? If the investments are different, what are those differences?

The money and time invested by the students was investigated in the project. To collect data, students were asked to record the time spent on the projects and the area where time was spent. The data was gathered for each of the major stages of the project including: preliminary development (research and sketching), drafting of final product, preliminary model construction, demonstration model construction, and presentation materials. An Excel (Microsoft Office 2003, Microsoft Inc.; Redmond, WA) spreadsheet was provided to the students for tracking purposes. Similarly, students were asked to account for the project costs and the area it was spent on with the areas being preliminary development (research and sketching), drafting of final product, preliminary model construction, demonstration model construction, and presentation materials. Examples of these tracking sheets are given in Appendices D and E. Each individual measure of time and money invested was analyzed for differences in assigned model construction techniques and for overall mean differences. Additionally, means for individual areas were analyzed. A comparative value of $10 per hour was calculated for pay rates of an intern in the design field, thus allowing means of overall expenditure to be analyzed for the two methods of model construction. See Appendices D and E for money and time accounting sheets.

Analysis of subproblem #4. Subproblem #4 was analyzed using an independent sample t test. The three individual activities of sketching, 3D CAD, and final model construction, as well as the total of all three factors were analyzed by the model construction technique. Likewise, materials and total costs were analyzed by model construction technique. The mean, standard deviation, standard error of the mean, and the probability values were reported. One-way analysis of variance tables (ANOVA) were computed for both time and cost factors. Both f-statistics and probability values for were reported the factors.

Subproblem #5. Does the availability of technology limit or enhance the design complexity? If the technology impacts the design capabilities, in which ways, and how great is this effect?

Students were assessed as to the influence of the available technology on the complexity of the design chosen. This was analyzed using self-reporting survey questions. All questions asked students to identify a level of agreement to a statement given. The agreement statement was given using the 4-point Likert scale as described in subproblem #1. The first two questions addressed the perception of the difficulty to construct their design using hand construction techniques and rapid prototyping techniques. The third question asked if the assigned method influenced the design. The difference of perception in construction difficulty between the two methods was analyzed regardless of assigned method. A second point of analysis was the influence of the assigned method on the design. This was examined as a comparison of the methods assigned and their potential to influence a design. Table 7 shows the questions addressing subproblem #5. Appendix A includes the questions in the order and format as found on the survey.

Analysis of subproblem #5. The perception of difficulty for model construction, and the effects of construction technique were evaluated to identify correlations between the two methods of model construction. This was done using a chi-square test for the same purposes and in the same manner as questions for subproblem #1.

Table 7

Questions Asked in the Survey Addressing Subproblem #5

Question	Strongly agree	Agree	Disagree	Strongly disagree	Did not use
1. I would consider my design difficult to build by hand.					
2. I would consider my design difficult to build using a rapid prototyping process.					
3. The method of construction (hand built or rapid prototyping) assigned to me influenced my design .					

Subproblem #6. What are the expectations and potential of rapid prototyping from the perspective of the instructors in the study, and how do expectations contrast to the observed events?

This case study was approached as an instrumental (research on a case to gain understanding of another case) case study (Carspecken, 1996; Silverman, 2005; Stake 1995) with the findings intended to be useful to educators with similar cases. This report accompanies the given description necessary to identify the uniqueness and potential commonality therein. The program and case study descriptions are given in Chapter IV. Generalizations to other cases are considered to be best examined by those with intimate knowledge of those cases (Carspecken). The purpose of this report is to provide the necessary data for the reader to do so. Several approaches and methods were utilized to collect data for this study.

To focus on instructors' perceptions and expectations, the majority of data collection relied on interviews and interactions with the instructors using the methodologies outlined by educational ethnographer Phil Carspecken (1996). Additional data contributing insight was gathered through observations and interactions with the instructors throughout the study. For the case description, the majority of the data collection was recorded as field notes using the methods of Silverman (2005). These field notes included observations by the researcher as well as those of the instructors. Artifacts and photographs were also collected to supplement the data. The artifacts included are: the instructional handouts given by the instructors, presentation lessons, and photographs documenting the activity.

Role of Researcher

It is important to understand the role of the researcher as being the central instrument in the case study (Stake, 1995). Although this report will approach the case study from grounded theory perspective, the disposition and experience of the author will be disclosed. Prior experience as a participant in the activity cannot be separated from the case study. The researcher has experience in both traditional construction techniques (woodworking) and computer aided drafting and manufacturing. The researcher values both aspects and did not intentionally look towards one method out of a personal preference and bias toward that method. Any bias may be approached as looking to combine the strengths of both methods. This bias includes a slight skepticism toward the full adoption of newer technology, thus losing the strengths of traditional methods. The researcher assumed a participant role in the case study (Wolcott, 1999). This role encompassed acting as a guide to students as one experienced in rapid prototyping and will required to attend the classes, as well as guiding students in using the rapid prototyping equipment.

Qualitative Data Analysis for Subproblem #6

The data was collected in a longitudinal layout (Cohen, 2008; Gall et al., 2003; Gravetter & Wallnau, 2005), and analyzed using a two phase process. The first phase was the collection of instructors' insights, perspectives, predispositions, and expectations. The second phase was the collection of data in the description of the events as they played out in the case. The analysis of each phase follows the methods as described by Silverman (2005).

Quantitative Data Analysis

All statistical analyzes were completed using SPSS statistical software (release 16.0.1; SPSS Inc.; Chicago, IL). For all questions, correlation of individual student responses was assumed between categories and/ or between model construction techniques and that correlation was rejected at a significance value of $\alpha < 0.05$. Values of $p < 0.05$ and $p < 0.15$ were noted in the text as being unclear to suggest a correlation or not. The main assumption to be was that the samples were drawn from the same population in a random fashion. To accommodate for potential differences to the population according to instruction, half of the students for each sample were drawn from each class. In reporting chi square analyzes, the p value of mean differences is given. In reporting t tests and normally distributed data, the mean values + the standard error of the mean was given. Additional statistical data such as the standard deviation and p values are reported in Appendix J.

Conclusions

The study identified the presence of differences, and where the differences existed and their nature between the two methods of model construction. Conclusions will address the impact of the differences on students' outcomes as measured in the end product. The purpose of the conclusion is to generate data for decisions in curriculum development by educators. The data will be analyzed according to the Standards for Technological Literacy (ITEA, 2002) and the professional standards set by the NCIDQ (2008). The analysis addressed the individual standards of both associations and identified potential for one method to meet the standards better. The evaluation utilized the qualitative data collected through observation, as well as data analyzed in the first five subproblems.

Protection of Students

This study was approved by the Institutional Review Board (IRB) at Utah State University. The confidentiality of the students was and will be maintained by not releasing student responses on an individual basis, and not releasing student names associated with any data. The students were coded to a responding number, and that number was used in all data analysis, and student names and responses were and will not be reported to teachers or departments. This was made clear to the students when the project was presented, on the letter of information (Appendix F), and on the survey (Appendix A).

Equal access to outside help was necessary to balance the data to the participants in the survey. To accommodate for this balance, all students regardless of method assigned were allowed help based on a first come basis. Students using traditional model making methods received additional help including the use of woodworking, soldering and metals manufacturing equipment.

CHAPTER IV

RESULTS

Chapter IV analyzed the data recorded from each instruments. Chapter V addresses each subproblem as defined in pervious chapters. Discussion of the data is addressed in Chapter V.

Survey Findings

The survey was completed by 21 students; the findings of the survey will be reported in four sections: demographics, design, affective traits, and open ended responses. The survey yielded 21 out of 46 students completing and submitting the survey. The lower than expected response rate has been attributed to the deadline of the project being the final day of class. The students were asked to respond at that time. Seventeen students completed the survey within three days, and four students completed the survey after a follow up e-mail was sent requesting student to complete the survey. Internet based surveys typically have a lower response rate than any other method (Fowler, 2002; Suskie, 1996).

Demographics/Population Data

The data addressing demographics and population data comes from observational notes, and survey data and public records. The source of each will be noted in describing the population.

Gender and Ethnicity

The student population was largely female (43 students) with there being only three male. All three male students were enrolled in the same class. This grouping appears coincidental as they did not sit adjacent nor work closely together. All students defined themselves as “White or Caucasian” on the survey. This gender ratio is typical of interior design programs (Caughey & Salley, 1993; Havenhand, 2004; Wood-Nartker, Sepansky, McCrady, & Gligor, 2007).

Age

The age of the majority of students is typical for traditional students in a sophomore-level university class. Two areas of note are the nontraditional students older than 28 and the lack of students between 22 and 27 years of age. In a cross-analysis of age and gender, two male students accounted for two of the three nontraditional students in the study. The age breakdown of the students is provided in Table 8.

Academic Experience

Academic experience paralleled the expectation of age and class level. The majority of students were classified as sophomores with some students having the credits

Table 8

Student Ages

Age	Percent
18-19	15.8
20-21	68.4
28-29	5.3
30-34	10.5

to be classified as juniors. One survey respondent was considered a senior and one was a master's level graduate student. Students' academic experiences are shown in Table 9.

Area of Study

The students are divided after the sophomore year into studio and marketing tracks to finish their degree. Only the studio track is accredited by the Council for Interior Design Accreditation. From public records, 20 students were accepted into the studio emphasis interior design program, 25 were accepted into the sales and marketing emphasis interior design program, and one student left the department (Wickham, 2008). Students with the strongest display of design talent were given preferential entry into the studio emphasis. The survey responses were twice as likely to be from the studio emphasis track as those who were sales and marketing focused. Table 10 shows the students' intended major.

Parent's Highest level of Education Achievement

Students were asked what the highest level of education achieved by a parent. This question was asked as a socioeconomic indicator as well as an indicator of family

Table 9

Students' Academic Experience

Grade	Percent
Sophomore	57.9
Junior	31.6
Senior	5.3
Graduate student – Masters	5.3

Table 10

Students' Intended Major

Area of study	Percent
Interior Design - Sales and Marketing	31.6
Interior Design - Studio	63.2
Other	5.3

value placed on education. The majority of students' parents have received a bachelor's degree with an exceptionally high number of graduate level degrees. The student's parent's highest level of education achieved is given in Table 11.

Design Influences—Design Tools

Students were asked which design tools influenced their design by agreeing or disagreeing to the statement: the following tools have influenced my design greatly; with a level of agreement to be selected from: strongly disagree, disagree, agree, strongly agree, and did not use. This question was asked for seven commonly used design tools. The results of individual questions are posted in Appendix I. The mean value and standard deviation are shown in Figure 1 for each of the factors.

Since preliminary sketches and final models were the only required design tools in the project, the number of students choosing not to use a particular tool is given in Figure 2.

Preliminary Sketches

Preliminary sketches were identified unanimously by students as an influential

Table 11

Highest Level of Education Achieved by Students' Parents

Education level	Percent
High School/ GED Diploma	5.3
Some College	15.8
College Graduate - Associates Degree	15.8
College Graduate - Bachelor's Degree	36.8
College Graduate - Graduate Degree	26.3

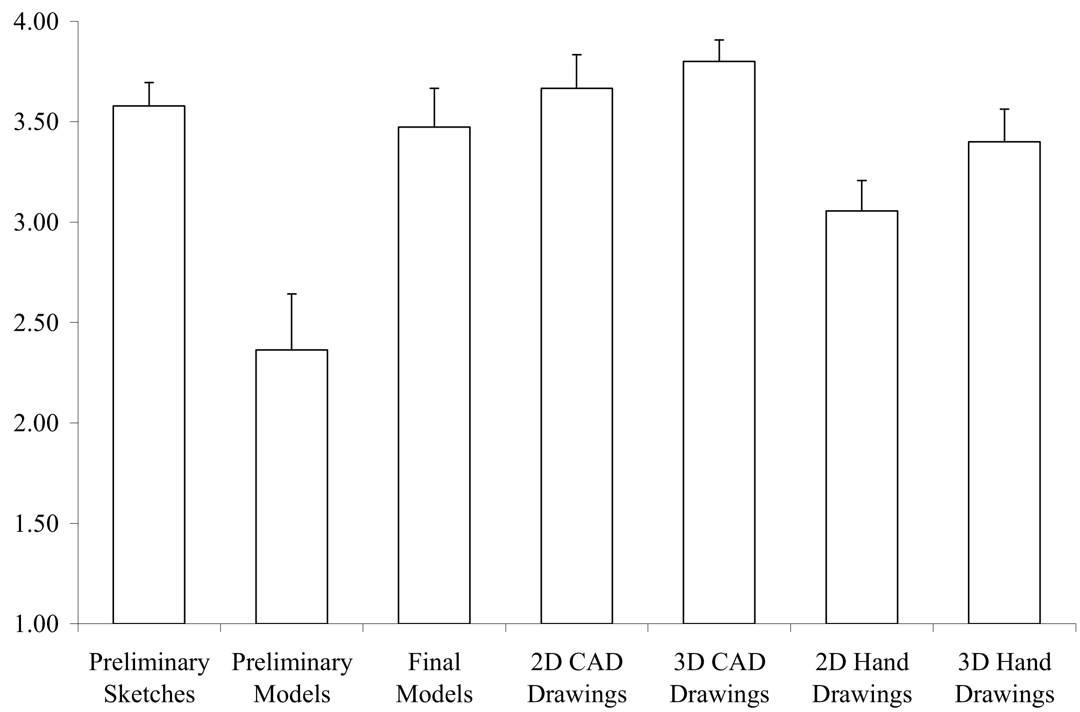

Figure 1. Response to the question "The following influenced my design." The graph shows mean response to each design activity with the standard error of the mean being shown as whiskers above the plot. A value of one represents strong disagreement with the statement and a value of four represents strong agreement with the statement.

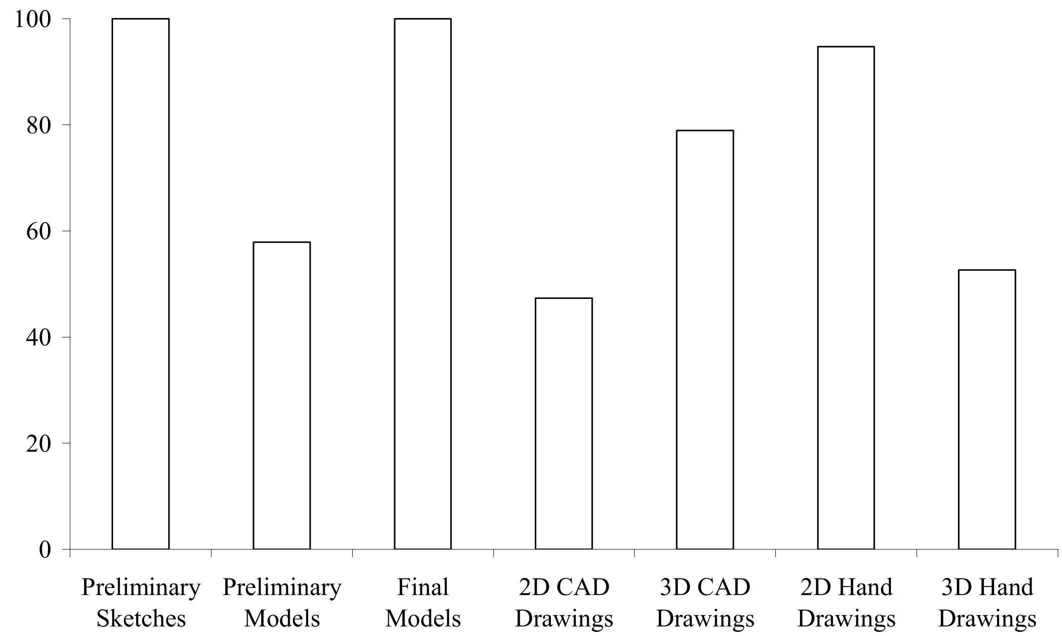

Figure 2. Percentage of students choosing to use each design activity in the project. Preliminary sketches and final models were explicitly required in the assignment. All other activities were not required.

part of the design process. The majority of students strongly agreed that preliminary sketches influenced their designs greatly.

Preliminary Model

The construction of the preliminary model should give students and designers feedback for the form, function, spatial relations and flow within a project (Frampton & Kolbowski, 1981; Janke, 1968; Starkey, 2006). Under this hypothesis, the construction of the preliminary model should have a great influence on the final design. Preliminary models were required by one class and not by the other class. Forty-two percent of the respondents did not use a preliminary model. Those who did use the model reported a greatly varied response in the effectiveness in the preliminary model. Overall responses showed preliminary models to be on of the least influential tools in the project.

Final Model

Final models are not expected to be a major influence in design as the majority of the design should have been explored prior to the creation of the final model (Frampton & Kolbowski, 1981; Janke, 1968). This should transfer into preliminary sketches, CAD and 3D hand drawings being more influential as indicated by the survey results.

CAD and Hand Drawings

Students were not required to develop their ideas beyond sketches, but have training and the available tools to do so (Wickham, 2008). Students who used rapid prototyping were required to design 3D CAD models. The breakdown of student responses for each tool is as follows:

2D CAD Drawings

The majority of students (53%) did not use 2D CAD drawings and the students who did use 2D CAD drawings were split between the influence they had in the design with a majority strongly agreeing that 2D CAD drawings influenced the design greatly, and a minority disagreeing with that statement.

3D CAD Drawings

Although 12 students were not required to model their project in 3D, 8 still chose to do so. Nearly all students strongly agreed that 3D CAD drawings influenced their design greatly.

2D Hand Drawings

The usage of 2D hand drawings yielded a stronger variety of responses than any other graphical method. Only one student reported not utilizing 2D hand drawings.

3D Hand Drawings

Forty-seven percent of students chose not to draw a 3D figure by hand. Of those who did, all agreed or strongly agreed that it influenced their design greatly.

Interpersonal Design Influences

Within most educational design settings, students receive feedback for design improvements, not only from themselves, but also from instructor, students, and other individuals. The following section is designed to identify the source and strength of the interpersonal design influences. The mean value and standard error of the mean are given in Figure 3 for each of the factors. Additionally, as each category of person did not contribute to the project, the number of students choosing not to use a particular type of person is given in Figure 4.

Instructors

With the instructor working closely with students on design, it was expected that they influenced the design. Most students agreed or strongly agreed that the instructor. influenced the design. One student did not consult with the instructor. One student disagreed that the instructor influenced their design.

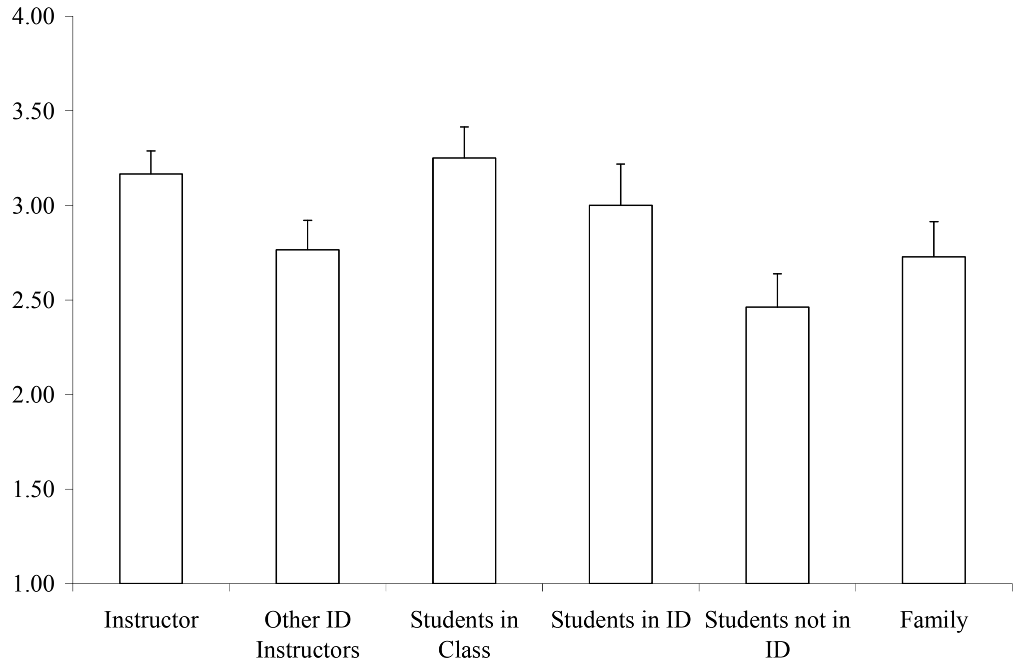

Figure 3. Response to the question: “The following people have influenced my design.” The graph show mean response to each source with the standard error of the mean being shown as whiskers above the plot. A value of 1 represents strongly disagreeing with the statement and a value of 4 represents strongly agreeing with the statement. Interior Design has been abbreviated to ID.

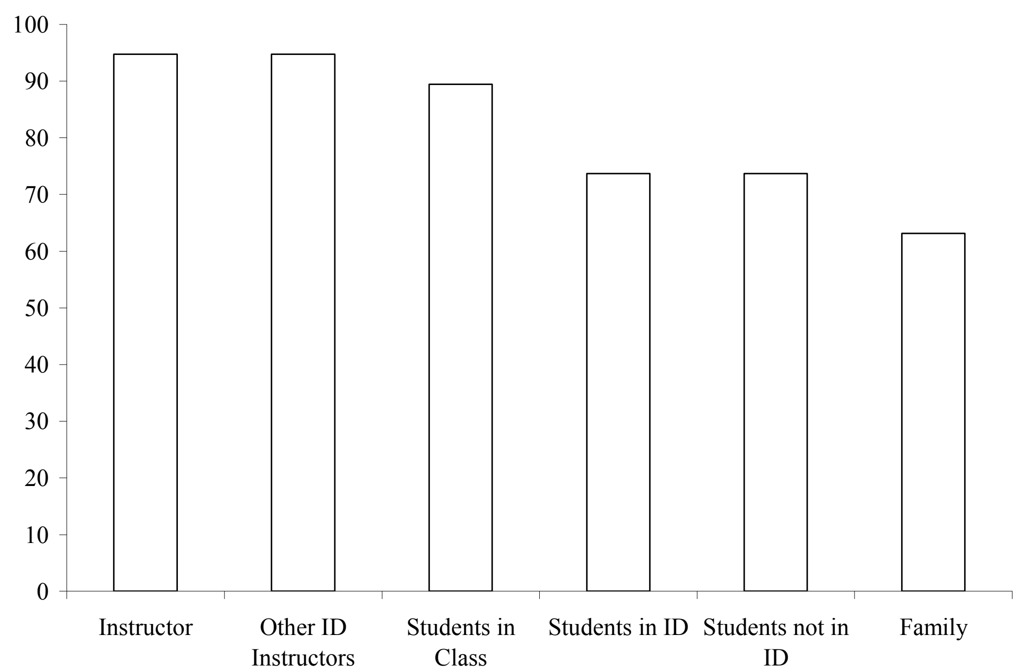

Figure 4. Percentage of students choosing to consult with other people during the project.

Other Instructors in Interior Design

Likewise, the impact other instructors within the department on the students' designs was investigated. Student responses indicated that other instructors did not influence the design significantly. An interesting note may be that disagreement to the statement may indicate not having consulted with other instructors on the project. Only two students stated that they did not utilize other instructors for this project.

Students within the Same Class

Throughout the project, most students collaborated with other students on the project voluntarily. Three students reported not consulting with other students in their class on the design, and most students consulted with other students in their major and throughout the university. The collaboration effect was greatest within the class.

Additional Persons of Influence

The final category was consultation with family member. Most students consulted with a family member on the project and indicated that the collaboration influenced their design. Additionally, students were asked to identify any person not previously specified, their level of influence and their relationship to the student. No additional persons were specified.

Effectiveness of Design Tools in Transferring Ideas

Students consult with other individuals to improve their designs. This section is designed to identify which tools were most effective in communicating those ideas. Similar to previous survey questions, students were asked to respond to a statement with a level of agreement. It is worth noting that not all tools were required by the students to complete the project and the survey provides for students to select that they did not use a particular tool. The findings for each method are described below and shown in Figure 5.

1. Preliminary Sketches – All of the students created preliminary sketches and agreed or strongly agreed that they influenced their design greatly. All students with one exception (strongly disagree), agreed or strongly agreed that preliminary sketches were effective in sharing information and ideas with others.

2. Preliminary Models – Preliminary Models were only required by one class, and 42% of students chose not to construct one. Of the students who constructed a

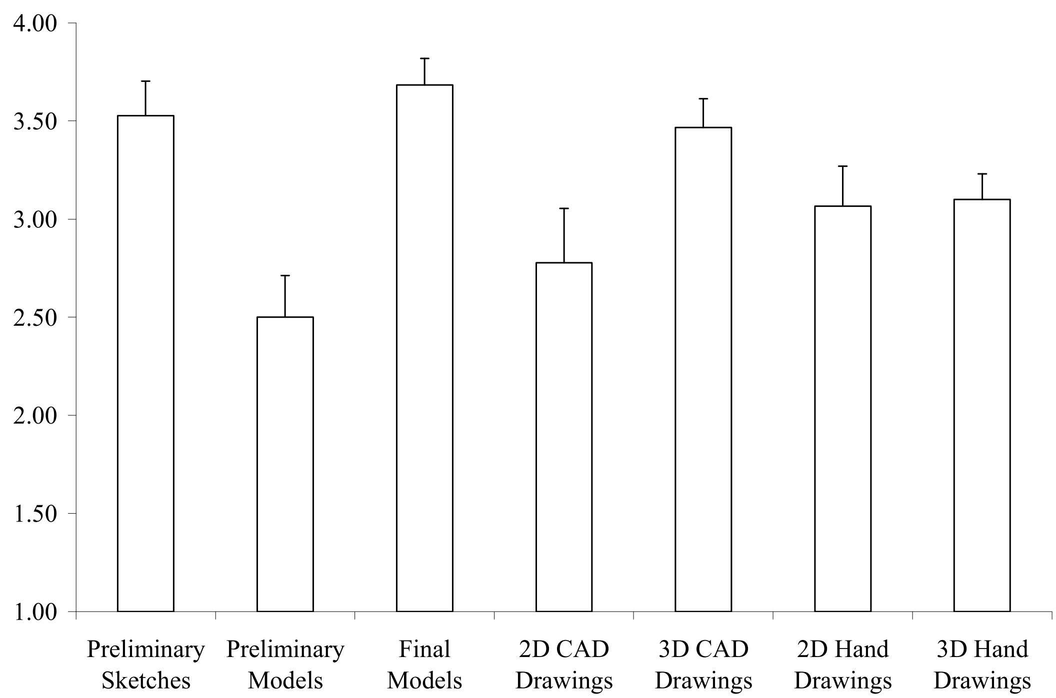

Figure 5. Response to the question: “The following were effective in transferring ideas.” The graph show mean response to each source with the standard error of the mean being shown as whiskers above the plot. A value of one represents strongly disagreeing with the statement and a value of four represents strongly agreeing with the statement. Preliminary sketches and final models were required in the project.

preliminary model, four additional students chose not to use it to share information and ideas. Few students considered it to be effective in sharing ideas.

3. Final Models – Nearly all students found their final model to be a strong communication tool in sharing ideas. Only one student disagreed with the final model being effective in transferring ideas.

4. 2D CAD Drawings – Students were not required to construct any CAD or hand drawings within the assignment. Many students chose not to create 2D CAD drawings. Of those that used 2D CAD drawings to share ideas, about two thirds found them to be effective.

5. 3D CAD Drawings – Most students created a 3D CAD model and all agreed or strongly agreed that it was effective in sharing ideas. Only one student stated the 3D CAD model was ineffective in sharing ideas.

6. 2D Hand Drawings – 2D hand drawings were utilized the most of any drafting method including 3D CAD models. The students reported a greater variance in the effectiveness of 2D hand drawings than of 3D CAD models and less strength in effectiveness.

7. 3D Hand Drawings – 3D hand drawings were utilized very seldom, but those who created a 3D hand drawing found the tool to be effective in sharing ideas.

Design Improvement

The question was posed whether the students feel that the quality of their design has improved throughout the project. As would be expected, nearly all students agreed or strongly agreed that the quality of their designs improved throughout the project. Two students disagreed or strongly disagreed. Both students who disagreed or strongly disagreed received lower marks on their design with scores of 10 and 7.75 out of 15. The mean for all students was 10.95 ± 0.55 on this variable. The students reported their level of agreement on Table 12.

Affective Disposition

The affective disposition section of the survey is designed in three parts, areas of enjoyment, areas of frustration, and values placed on processes and tools. These traits are selected because areas of enjoyment correlates with better performance, personal satisfaction in the project, and likeliness that students will utilize similar practices and tools in future projects and professional careers (Hansen, 1995). Likewise, frustration correlates with lower performance, personal satisfaction in the project and likeliness that students will utilize similar practices and tools in future projects and professional careers (Krathwohl et al. 2001; Ormrod, 1999; Kosslyn & Rosenberg 2003). Similarly, values are built from experiences, and are an indicator of students' future professional practices. The

Table 12

Overall, I Feel the Quality of My Design Has Improved Throughout the Project

Response	Percent
Strongly agree	26.3
Agree	63.2
Disagree	5.3
Strongly disagree	5.3

mean values and standard error of the means for enjoyment, frustration, probable professional use, and value are given in graphs in Appendix K for each of the factors. A summary of the responses to each question are given in Figure 6.

Preliminary Sketches

Preliminary sketches represent the brainstorming and initial creative stages of the design process (Bertoline, Weibe, Miller, & Nasman, 1995). The majority of students agreed or strongly agreed to enjoying creating preliminary sketches, while a strong

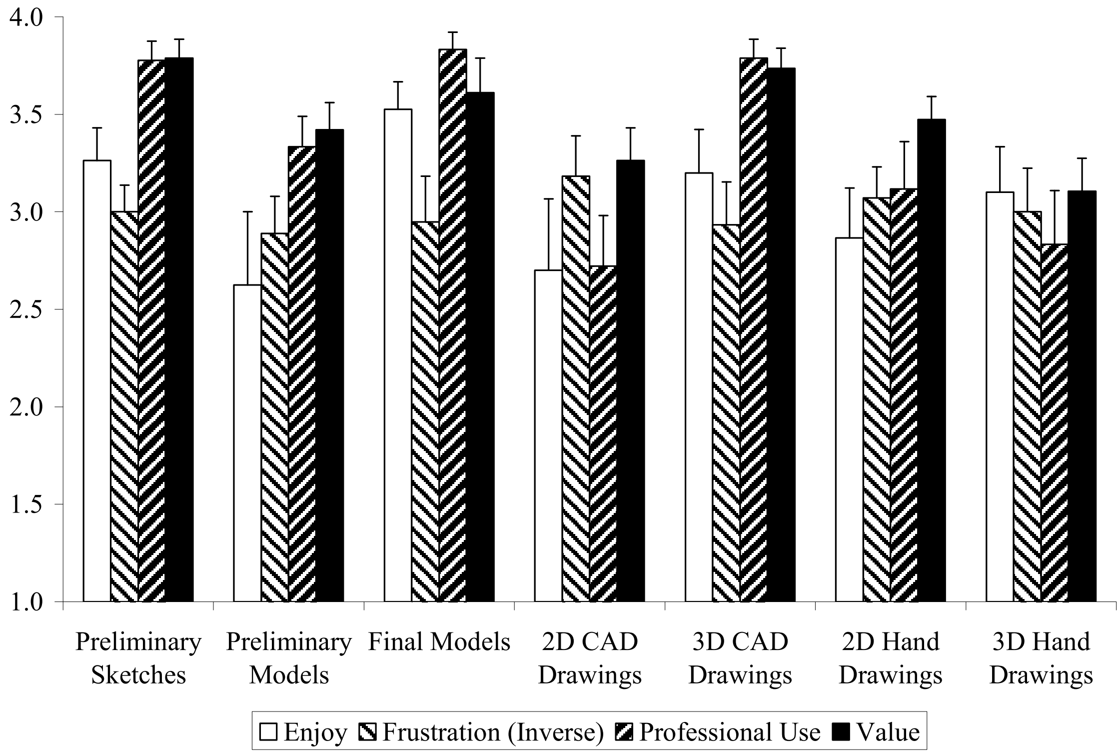

Figure 6. Mean responses to all affective trait questions. The questions were: 1. I enjoy doing the following: 2. I was frustrated in doing the following: 3. If I were faced with a similar design project as a professional after graduation, I would likely create a: and 4. As a student learning about design, I find the following to be valuable: The graph shows mean responses to each source with the standard error of the mean being shown as whiskers above the plot. A value of 1 represents strong disagreement with the statement and a value of 4 represents strong agreement with the statement. This coding is reversed for the question regarding frustration.

majority of students disagreed with experiencing frustration in creating preliminary sketches.

From the cross tabulation of enjoyment and frustration in creating a preliminary sketch, no clear correlation is shown. This is supported by a Pearson chi-square test with a highly insignificant *p* value ($p < .656$). The data show insignificance due to the large number of students disagreeing with experiencing frustration in creating preliminary sketches and a small sample size. All students agreed or strongly agreed to preliminary sketches being valuable in design and would likely create a preliminary model as a design professional. Table 13 shows the cross tabulations.

A cross tabulation (Table 14) of projected professional use and value yields a correlation that students who place a higher value on preliminary models would be more likely to create them in a professional scenario. This show to be statistically significant ($p < .043$) using a Pearson chi-square test.

A similar cross tabulation (Table 15) of student's value versus enjoyment in creating preliminary sketches shows correlation with a highly statistically significant *p*

Table 13

Enjoyment Versus Frustration in Preliminary Sketches Cross Tabulation

	Frustration			
Enjoyment	Strongly agree	Agree	Disagree	Strongly disagree
Strongly agree	0	1	5	2
Agree	0	1	6	1
Disagree	0	1	1	0
Strongly disagree	0	0	0	0

Table 14

Professional Use Versus Value in Preliminary Sketching Cross Tabulation

	Value			
Professional use	Strongly agree	Agree	Disagree	Strongly disagree
Strongly agree	13	1	0	0
Agree	2	2	0	0
Disagree	0	0	0	0
Strongly disagree	0	0	0	0

Table 15

Value Versus Enjoyment in Preliminary Sketching Cross Tabulation

	Value			
Enjoyment	Strongly agree	Agree	Disagree	Strongly disagree
Strongly agree	8	0	0	0
Agree	7	1	0	0
Disagree	0	3	0	0
Strongly disagree	0	0	0	0

value ($p < .001$) using a Pearson chi-square test. An additional cross tabulation (Table 16) of enjoyment versus professional use in preliminary sketches show correlation with a statistically significant p value ($p < .009$) using a Pearson chi-square test.

Preliminary Model

Many students did not use preliminary models, and the students who did reported a strongly varied level of enjoyment in creating these models while most students disagreed with experiencing frustration while creating the preliminary models. In a cross

Table 16

Professional Use Versus Enjoyment in Preliminary Sketches Cross Tabulation

	Professional use			
Enjoyment	Strongly agree	Agree	Disagree	Strongly disagree
Strongly agree	8	0	0	0
Agree	6	2	0	0
Disagree	0	2	0	0
Strongly disagree	0	0	0	0

tabulation of frustration versus enjoyment, a small pattern appears. This pattern is slightly insignificant ($p < .072$) on a Pearson chi-square test. The sample size is too small (7 reporting having created a preliminary model on both questions) for any conclusive strength. A chart of the cross tabulation is shown in Table 17.

The majority of students reported that they found preliminary models to be valuable and would likely create a preliminary model if faced with a similar project as a professional. In spite of this claim, nearly 58% of students chose not to build a preliminary model on this project. A cross tabulation (Table 18) of enjoyment and the probable use in a professional setting for preliminary models shows a visual trend, but is slightly statistically nonsignificant ($p < .070$) due largely to a small sample size of seven. Cross tabulations of professional use versus value, and enjoyment versus value show a slight visible trend but yield statistically nonsignificant p values ($p < .339$ and $p < .273$).

Final Models

Contrary to one instructor's expectations and open-ended survey responses that

Table 17

Enjoyment Versus Frustration in Preliminary Models Cross Tabulation

	Frustration			
Enjoyment	Strongly agree	Agree	Disagree	Strongly disagree
Strongly agree	0	0	2	0
Agree	0	0	2	0
Disagree	0	0	2	0
Strongly disagree	0	1	0	0

Table 18

Professional Use Versus Enjoyment in Preliminary Models Cross Tabulation

	Professional use			
Enjoyment	Strongly agree	Agree	Disagree	Strongly disagree
Strongly agree	2	0	0	0
Agree	1	1	0	0
Disagree	0	2	0	0
Strongly disagree	0	0	1	0

some students hate building models, students reported enjoying creating the final model. A majority of students disagreed or strongly disagreed with experiencing frustration in creating a final model and a correlation (Table 19) was shown to exist between enjoyment and frustration ($p < .043$).

All students strongly agreed or agreed (with one exception) to finding final models to be valuable and would likely use them in a similar project as a professional. In a cross tabulation, no direct correlation was found linking professional use and value ($p < .668$).

Table 19

Enjoyment Versus Frustration in Final Model Cross Tabulation

	Frustration			
Enjoyment	Strongly agree	Agree	Disagree	Strongly disagree
Strongly agree	11	2	1	0
Agree	2	1	0	0
Disagree	0	0	0	0
Strongly disagree	0	0	0	0

A slightly nonsignificant ($p < .076$) was shown in a cross tabulation between value and enjoyment in the final model construction. This is show in Table 20. Likewise, a statistically significant ($p < .017$) correlation was shown in a cross tabulation of professional use versus enjoyment. This is presented in Table 21.

2D CAD Drawings

The majority of students did not create a 2D CAD drawing, and those who did reported an evenly distributed enjoyment of creating 2D CAD drawings. No visual trend was displayed between enjoyment and frustration in 2D CAD drawings, and a Pearson chi-square test shows no statistical significance ($p < .257$). The majority of students reported valuing 2D CAD drawings; however, students reported a variety of responses in creating 2D CAD drawings as a professional in a similar project. In a cross tabulation and comparison (Table 22), a correlation was shown between enjoyment and probable professional use ($p < .050$). A visual trend was exhibited between enjoyment and value (Table 23) with a nonsignificant p value ($p < .149$) and similarly between probable professional use and value (Table 24; $p < .107$).

Table 20

Enjoyment Versus Value in Final Model Cross Tabulation

	Value			
Enjoyment	Strongly agree	Agree	Disagree	Strongly disagree
Strongly agree	9	0	0	1
Agree	4	3	0	0
Disagree	0	1	0	0
Strongly disagree	0	0	0	0

Table 21

Enjoyment Versus Professional Use in Final Model Cross Tabulation

	Professional use			
Enjoyment	Strongly agree	Agree	Disagree	Strongly disagree
Strongly agree	11	0	0	0
Agree	4	3	0	0
Disagree	0	0	0	0
Strongly disagree	0	0	0	0

Table 22

Enjoyment Versus Professional Use in 2D CAD Drawings Cross Tabulation

	Professional use			
Enjoyment	Strongly agree	Agree	Disagree	Strongly disagree
Strongly agree	3	0	0	0
Agree	0	3	0	0
Disagree	1	0	0	0
Strongly disagree	1	0	1	0

Table 23

Enjoyment Versus Value in 2D CAD Drawings Cross Tabulation

	Value			
Enjoyment	Strongly agree	Agree	Disagree	Strongly disagree
Strongly agree	3	0	0	0
Agree	1	2	0	0
Disagree	0	2	0	0
Strongly disagree	1	1	0	0

Table 24

Value Versus Professional Use in 2D CAD Drawings Cross Tabulation

	Value			
Professional use	Strongly agree	Agree	Disagree	Strongly disagree
Strongly agree	5	1	0	0
Agree	1	3	0	0
Disagree	1	3	0	1
Strongly disagree	0	3	0	0

3D CAD Drawings

The majority of students chose to model their design in a 3D CAD program. Interior design students have considerable exposure to 3D CAD modeling and were completing their second course dedicated to 3D CAD modeling (Wickham, 2008). Students strongly reported enjoying, valuing and intend on using 3D CAD drawings in a professional setting while a minority of students experienced frustration in creating 3D CAD drawings. In a cross tabulation (Table 25), significance was only shown in enjoyment versus frustration ($p < .017$). All other cross tabulations showed to be statistically nonsignificant and show no distinct pattern visually.

Table 25

Enjoyment Versus Frustration in 3D CAD Drawings Cross Tabulation

	Frustration			
Enjoyment	Strongly agree	Agree	Disagree	Strongly disagree
Strongly agree	0	0	4	2
Agree	0	2	2	2
Disagree	1	0	0	0
Strongly disagree	0	1	0	0

2D Hand Drawings

Students reported a more evenly distribution of enjoyment and frustration in creating 2D hand drawings than other categories represented in the survey. Similar results were reported for probable use as professional facing a similar project. All students agreed to valuing 2D hand drawings.

In a cross tabulation, no correlation was found visible or statistically ($p < .844$) comparing enjoyment with frustration in creating 2D hand drawings. A correlation comparing enjoyment and probable professional use (Table 26) was found both visibly and statistically ($p < .013$). A visible and slightly statically nonsignificant ($p < .064$) correlation was found contrasting enjoyment and value in creating 2D hand drawings (Table 27) as well as probable professional use and value (Table 28; $p < .124$)

3D Hand Drawings

For this project, the majority of students decided not to create a 3D hand drawing. The use of 3D hand drawings in the assignment would be for visualization, as other methods would be employed for production purposes. In a comparison to 3D CAD

Table 26

Enjoyment Versus Professional Use in 2D Hand Drawings Cross Tabulation

	Professional use			
Enjoyment	Strongly agree	Agree	Disagree	Strongly disagree
Strongly agree	3	0	4	0
Agree	3	4	0	0
Disagree	1	1	0	0
Strongly disagree	0	0	1	0

Table 27

Enjoyment Versus Value in 2D Hand Drawings Cross Tabulation

	Value			
Enjoyment	Strongly agree	Agree	Disagree	Strongly disagree
Strongly agree	4	0	0	0
Agree	2	5	0	0
Disagree	1	1	0	0
Strongly disagree	0	2	0	0

Table 28

Professional Use Versus Value in 2D Hand Drawings Cross Tabulation

	Value			
Professional use	Strongly agree	Agree	Disagree	Strongly disagree
Strongly agree	6	2	0	0
Agree	1	4	0	0
Disagree	0	2	0	0
Strongly disagree	1	1	0	0

drawings, six of the nine students who did not create a 3D hand drawing created a 3D CAD drawing leaving only three students without a 3D visual representation before constructing a model. Of the three students without a 3D visual representation, two chose to construct a preliminary model leaving one student without a 3D representation before constructing the final model. Student responses concerning affective traits and 3D hand drawings are represented below. In a cross tabulation of enjoyment and value (Table 29), a visual trend is exhibited with a slightly nonsignificant value ($p < .091$). No other combinations exhibited either a strong visual or a statistically significant trend.

Model Construction Perception

Three questions were asked to all students regarding their design and model construction methods. Two questions asked how difficult they perceive their designs to be built in both the traditional hand built method, as well as with a rapid prototyping technique. The third question addressed whether the assigned method influenced their design. The majority of students considered their design as difficult to build by hand,

Table 29

Enjoyment Versus Value in 3D Hand Drawings Cross Tabulation

	Value			
Enjoyment	Strongly agree	Agree	Disagree	Strongly disagree
Strongly agree	3	0	0	0
Agree	1	4	0	0
Disagree	1	1	0	0
Strongly disagree	0	0	0	0

while the majority of students disagreed with their model being difficult to build through a rapid prototyping technique. This is shown in Tables 30 and 31.

The majority of students agreed or strongly agreed that the method assigned to the (rapid prototyping or hand built) project had an effect on their design (Table 32). While students reported the method assigned as having an influence on their design, no significant difference ($p < .869$) was shown when comparing the rapid prototyping group against the traditional hand built group.

Table 30

I Would Consider My Design Difficult to Build by Hand

Response	Percent
Strongly agree	31.6
Agree	36.8
Disagree	31.6
Strongly disagree	0

Table 31

I Would Consider My Design Difficult to Build by Using a Rapid Prototyping Process

Response	Percent
Strongly agree	10.2
Agree	26.3
Disagree	21.1
Strongly Disagree	42.1

Table 32

The Construction Method Assigned to Me Influenced My Design

Response	Percent
Strongly agree	21.1
Agree	47.4
Disagree	26.3
Strongly Disagree	5.3

Open-Ended Responses

The survey concluded with a two open-ended response questions. The first question asked students: What was the most positive aspect of creating a model? Responses to this question were coding according to methods outlined by Carspecken (1996). Coding identified two major and four minor themes as determined by frequency counts reported. All students responded with two students entering data containing multiple themes. The coded responses for the open-ended response section are given in Appendix L.

The first major theme identified by students as the most positive aspect of creating a model was having a physical representation of their design and ideas. Eight students identified the satisfaction of the finished product to be the crowning moment of the project. The second major theme identified was the design process. Six students identified aspects of designing from the preliminary design stages through revising and construction to be the most positive aspect of creating the model. The quality of rapid prototyping combined with the ease of construction was identified by two students. One of the two students who identified the project being easier than expected use a rapid prototyping machine. One student identified the ease of rapid prototyping to be a positive aspect in the project. Two students identified learning aspects as the most positive part of the assignment. These aspects include ergonomic and construction techniques. One student reported a change of pace from the typical projects found in the program to be the most positive aspect of the project. All responses are posted below in the respective coded themes.

Conversely, students were asked: What was the most negative part of creating a model? Two major themes emerged of frustrations in construction or CAD, and the amount of time invested into the project. All students reporting frustrations in CAD were students who used rapid prototyping, and all students who reported frustration in construction were students who used traditional hand techniques. Related to frustrations in construction, two students reported not being selected for the rapid prototyping group to be the negative aspect of the project. The amount of time and or money invested into the project was reported as another negative aspect of the project. Both money and time were evenly represented by rapid prototyping and hand construction students. Two students identified frustrations associated with design revision as being the most negative aspect of the project. One student did not respond to the question and one student answered “n/a” to the question. Both students used rapid prototyping.

Model Grading

In the research experiment, the classroom summative assessment was the creation of a finish presentation model. The instrument was the grading rubric found in Appendix

B. The grading rubric was separated into three parts addressing scale, design, and craftsmanship with design being the most important aspect and was identified in the Interior Design program goals (Wickham, 2008). It was decided that scale and craftsmanship be approximately equal in weight within the assessment, and design should be approximately 50% more heavily weighted. The areas of scale and craftsmanship had 10 points possible identifying five key expectations to meeting the standards of the program. The area of design had fifteen points possible to reflect the stronger evaluation emphasis on design quality of the assignment. The rubric allowed for two points per expectation in scale and craftsmanship and three points per expectation in design. The rubric allowed for scores to be adjusted to a one quarter of a point (0.25) to allow for a more continuous scale (Gronlund, 2006; McKeachie & Svinicki, 2006). The expectations were identified by the instructors as being essential elements in the project based on program goals and CIDA accreditation standards.

Three evaluators were used in the assessment to minimize the impact of any individual evaluator's bias (Rossi et al., 1999). Evaluators were asked to evaluate all models. However, all models were not available to all evaluators due to some models being handed in late, and one evaluator was unable to grade all models due to external circumstances. A summary of mean scores for each evaluator and the category evaluated is given in Table 33.

To assess concerns of interobserver reliability, comparative data for identical observations is required (Gravetter & Wallnau, 2005; Moore & McCabe, 2006; Oehlert, 2000). To assess the interobserver reliability, a series of paired sample *t* tests were conducted of the individual scores in the respective categories. These tests show a very

Table 33

Comparison of Evaluators' Mean Scores

	Scale	Design	Craftsmanship	Total Score
Evaluator 1	7.75	8.18	7.03	22.76
Evaluator 2	7.87	12.29	7.16	27.14
Evaluator 3	8.03	12.32	7.63	27.98
Mean of evaluators	7.88	11.04	7.46	25.96

high level of nonsignificance between evaluators in the areas of scale and craftsmanship making a case for high interobserver reliability. Within the area of assessing design, evaluator 1 was statistically significantly different from evaluators 2 and 3. This can be attributed to personal subjectivity in evaluating design and is to be expected to some degree (Huot, 1990; Penny, Johnson, & Gordon, 2000). In a comparison of total score, evaluator 1 was statistically different than evaluators 2 and 3 primarily due to differences in design scores. This is shown in Table 34.

A comparison of evaluator scores is given on the line graph below. Evaluator 1 consistently graded lower than both evaluators 2 and three. With a shift (linear transformation; Carspecken, 1996; Creswell, 2007; Denzin & Yvonna, 1998; Gravetter & Wallnau, 2005; Moore & McCabe, 2006; Oehlert 2000; Stake, 1995) of four points (the difference of means in evaluator1 and evaluators 2 and 3) being applied to evaluator 1, the comparative graph is shown in Figure 7. The sum of variance for the scores in design was 136.5 points. After that shift, the sum of variance was reduced to 69.83. The variance either remained the same, or was lowered in all but two cases.

Table 34

Paired Sample t *Tests for Interrater Reliability*

Evaluator	Mean difference	*SD*	Std. error mean	Sig. (2-tailed)
Scale				
Evaluator 1 vs. Evaluator 2	-0.1	2.08	0.37	0.781
Evaluator 1 vs. Evaluator 3	0.21	1.9	0.47	0.653
Evaluator 2 vs. Evaluator 3	0.02	2.07	0.48	0.955
Design				
Evaluator 1 vs. Evaluator 2	-4.12	3.35	0.6	0.001
Evaluator 1 vs. Evaluator 3	-3.12	3.79	0.94	0.005
Evaluator 2 vs. Evaluator 3	1.22	3.25	0.76	0.13
Craftsmanship				
Evaluator 1 vs. Evaluator 2	0.19	1.93	0.35	0.591
Evaluator 1 vs. Evaluator 3	0.18	1.49	0.38	0.642
Evaluator 2 vs. Evaluator 3	-0.06	1.58	0.37	0.855
Total score				
Evaluator 1 vs. Evaluator 2	-3.95	5.95	1.08	0.001
Evaluator 1 vs. Evaluator 3	-3.17	6.3	1.57	0.063
Evaluator 2 vs. Evaluator 3	0.98	5.52	1.33	0.472

The sum of squares for the scores in design was 136.5 points. After that shift, the sum of squares was reduced to 69.83. The variance either remained the same, or was lowered in all but two cases. In comparing the difference of evaluators after the shift, no significant difference was shown in the paired sample *t* tests giving strength to interobserver reliability. These tests are given in Table 35.

Money and Time Comparisons

Students were asked to account for the money and time invested into the project.

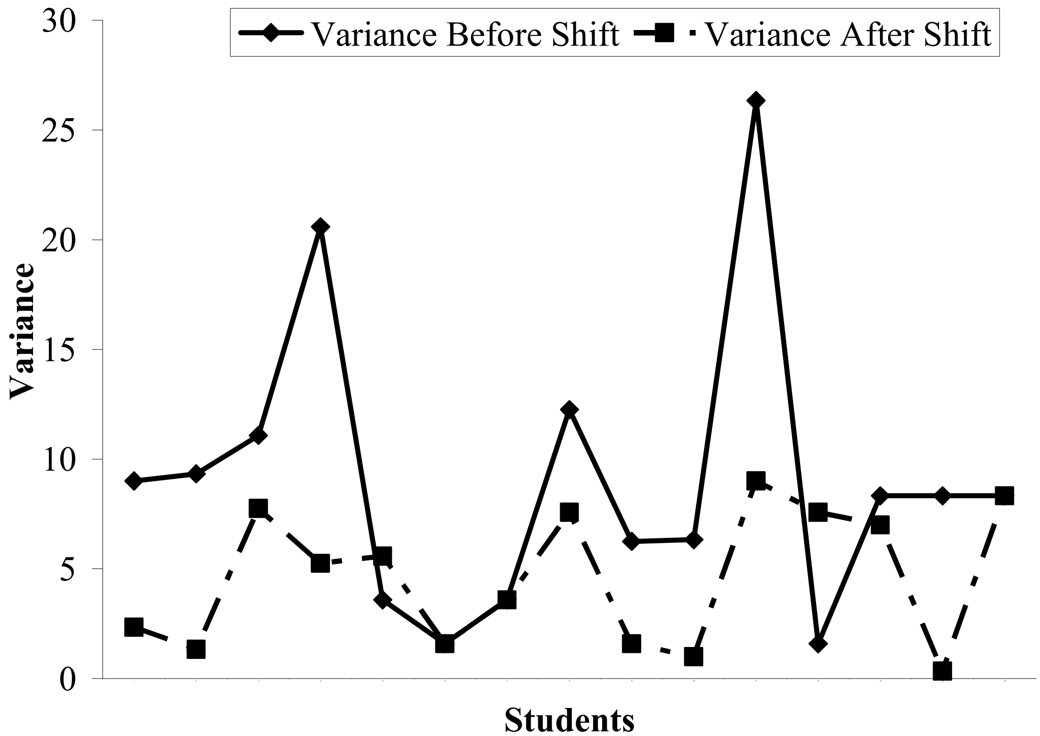

Figure 7. Line graph of variance in evaluators' scores for design by student. The diamond shaped series represents the variance before the shift of four points to scores given by evaluator 1. The square shaped series with a dashed line represents the variance after that shift.

Table 35

Paired Sample t *Tests for Interrater Reliability after Shift*

Evaluator	Mean difference	*SD*	Std. error mean	Sig. (2-tailed)
Scale				
Evaluator 1 vs. Evaluator 2	-.25	3.21	.56	.652
Evaluator 1 vs. Evaluator 3	.55	3.23	.78	.490
Evaluator 2 vs. Evaluator 3	1.14	3.18	.73	.135
Total score				
Evaluator 1 vs. Evaluator 2	-.09	5.80	1.04	.931
Evaluator 1 vs. Evaluator 3	.43	5.73	1.39	.757
Evaluator 2 vs. Evaluator 3	.84	5.38	1.26	.514

Twenty students accounted for time and/ or money investments. Overall factors of time and money will be reported, followed by individual factors and a summative value of the project based on project cost and time equivalent value of an intern.

Total Time Invested

Students reported a broad spectrum of time invested into the project ranging from four hours to nearly 24 hours of time on the 2-week project. Descriptive statistics are given in the Table 36. Graphing the interaction of total time invested versus average finished model score yields no visible correlation and regression statistics show a very weak correlation. An analysis of variance (ANOVA) is given for the two factors below. This test shows that nearly all of the variance is shown in the residuals (error term). The regression model accounts for very little of the variance and is statistically nonsignificant.

Preliminary Sketching and Conceptualization

Similarly to total time, preliminary sketching and conceptualization had a wide spectrum of time invested into the project ranging from a half hour to 7 hours of time

Table 36

Descriptive Statistics for Time and Money Comparisons

	Median	Minimum	Maximum	Mean	*SD*	Std. error of the mean
Time spent sketching	2.5	0.5	7	2.64	1.9	.42
Time spent in 3D CAD	3	0.5	9	3.83	2.51	.51
Time spent on final model	3.5	0.2	12.5	4.68	3.37	.75
Total dollars invested	25	1	68	28.45	19.72	5.69
Total value invested	133	79	293	155	69.5	17.94

on the 2-week project. Three students reported not spending a significant amount of time sketching/ conceptualizing. Virtually no correlation was visually detectable between time spent sketching and finish model grades. An ANOVA yielded a low r^2 value (.05) and a highly nonsignificant p value ($p < .794$) Descriptive statistics are given in Table 36.

3D CAD Design

3D CAD design work had a strong variance ranging from a half hour to nine hours. Five students reported not spending a significant amount of designing with a 3D CAD system. Virtually no correlation was visually detectable between time spent designing with 3D CAD and finished model grades. An ANOVA yielded a low r^2 value (.031) and a highly nonsignificant p value ($p < .531$) Descriptive statistics are given in Table 36.

Final Model

The final model accounted for the proportionally largest time investment of any individual factor, and like the other factors had a strong variance ranging from a half hour to nine hours. Virtually no correlation was visually detectable between time spent working on the final model and finished model grades. An ANOVA yielded a low r^2 value (.083) and a nonsignificant p value ($p < .231$) Descriptive statistics are given in Table 36.

Other Time Factors

No other categories were reported as having spent a significant amount of time by the majority of students. Eight students reported spending a significant amount of time working with their advertisement ranging from a half hour to 4 hours with a median time of just under 2 hours. Only three students reported spending time with 2D CAD drawings. All three were for about an hour. Two students reported spending time revising their design. Both students reported spending less than an hour doing so.

Total Money Invested

Students reported a large range of money invested into the project ranging from \$1 to \$68. Eight students did not report the cost of the model. Virtually no correlation was visually detectable between money spent on the final model and finished model grades. An ANOVA yielded a moderate r-squared value (.20) and a slightly nonsignificant p value ($p < .168$). Any conclusion to a presence or absence of a correlation would require a greater sample size than the 12 students represented.

Individual Categories of Monetary Investment

Two students reported spending money on equipment to complete the final model. These costs were ten and thirteen dollars respectively. The final category of money investment was materials used in the model construction. With a minimal impact from tool cost, money spent of the final model closely reflects total money invested.

Total Value Invested

A derived category of value was analyzed for a correlation to the final model grade. This category of value gives a monetary value to time based on the expected pay of an intern at a design office. The value of \$10 per hour was assigned from data provided by median income of several related professions. This information was provided in Chapter II. Similar to total time and money invested, no correlation was visible between value and model grade. An ANOVA yielded a low r^2 value (.033) and a highly nonsignificant p value ($p < .591$).

Case Study Data

The case study collected data from multiple sources or triangulation (Carspecken, 1996; Creswell, 2007; Denzin & Yvonna, 1998; Stake, 1995). The data have been coded into several underlining topics from the original sources. The sources are presented in the appendix as: observation notes (Appendix H), interview transcripts (Appendix G), curriculum handouts (Appendix C), and public information such as the university's program website (Wickham, 2008). The analysis of each phase follows the methods as described by Silverman (2005). The purpose of the case study data is to provide the contextual basis for transferability of results to other cases (Stake).

For the first phase, the major themes that arose were: expecting the technology to improve communication and increase possible designs, identifying student populations which may perform better with the technology, and potential hurdles to the curriculum with rapid prototyping.

The second phase identified trends as a response to the first phase data. The trends identified included: how design and communication was affected by rapid prototyping, how student populations responded to the technology, and the description of the activities included in the project. In addition to the trends which were specifically investigated, several trends emerged unanticipated. These trends included: enthusiasm for the technology and project combined with an early initiative, and trends and indicators into the demeanor of the program. Descriptions of the program and case study are necessary to evaluate the applicability to other cases and programs (Stake, 1995). The data necessary to do that is provided below.

The Program

To fully understand the case study, an appropriate awareness of the program setting and goals is requisite. The Interior Design Program is located at Utah State University under the College of Humanities, Arts, and Social Sciences. The faculty are quick to point out the differences between interior design and interior decorating. Several of these differences include: educational and professional rigor, professionalism, and interior construction knowledge. Interior designers are considered to design and create interior space. This view is also held by leading interior design organizations (CIID, 2005).

In addition to educational and occupational differences, interior designers are required to take certification exams in many states and obtain licensure in order to practice as a licensed interior designer. As of April 2008, this included 23 US states. (NCIDQ, 2008)

The Interior Design Program at USU has a great desire to continue to increase their high level of professionalism and rigor, while at the same time creating the representation of the program as it is. The perception of the program throughout the University does not match the competitive, high standard achieved by the program in the eyes of many faculty members. One hope and expectation that the addition of rapid prototyping may bring to the program is evidence of the strengths, rigor, and quality of the program. One instructor notes the potential of rapid prototyping as a recruitment tool with potential students exclaiming, “Interior design students do that!”

Program Organization

The degree offers two tracks, a studio emphasis and a sales and marketing emphasis. These tracks are identical through the sophomore year, and then divide for the junior and senior year. Upon first glance, it appears that the two tracks are intended to create the best fit for the student population. While this is true for some students, upon immersion into the program, it is clear that for the majority of students the desire is to be selected within the studio track.

The number of students admitted into the studio track is limited by the availability of space, faculty, and resources. This limit has been set to twenty students admitted per year. To identify the most qualified students for the studio track, a rigorous review is carried out at the end of the sophomore year. This review includes examination of: grade point averages, continuous enrollment in the program, and heavily upon performance in twelve art and interior design courses. Areas of consideration include quality of work, potential, and originality. The students are evaluated by faculty members and practicing professionals within the field of interior design. Requirements are also established for admittance into the sales and marketing track. Some students do not meet the minimum requirements for either program. Although both tracks offer degrees in Interior Design, some students do not acknowledge the sales and marketing track as admittance into the program, as the majority of the coursework therein is business and marketing related and not design based. Only the studio track is accredited through the National Council for

Interior Design Qualifications (NCIDQ, 2008; Wickham, 2008).

Influence of Visiting Designers

The program invites several distinguished designers to visit the program each year. One such visit that has left a major impression on the program came from accomplished designer Karim Rasheed when he visited in December of 2007. All faculty members have commented on the visit as being monumental, and the effects of his visit can be seen in student projects. The faculty has been clear to quote him as stating that he does not know what he or his firm would do without a rapid prototype machine. This has encouraged the faculty to push rapid prototype usage.

The Case Study

For this case, a sophomore level interior design course entitled “Space Planning and Human Dimensions” incorporated rapid prototyping technology into an existing curriculum for the first time this spring. Approximately half of each class used each method. The researcher assisted the students in rapid prototyping. There are two sections of this course taught by two separate instructors. Both instructors have taught previous sections of the course.

A major assignment within the course was the design and marketing of an original chair. As part of this, a physical scale model is required. The model was expected to be of high quality for the appropriate marketing of the chair. The quality of the model design and its craftsmanship were areas of grading consideration (educational objectives). There were no limits for material selection as long as the material reflects the visual intentions.

The assignment took three weeks of the course's curriculum. The first week was focused on design, the second week was focused on model construction, and the final week was focused on marketing of the chair. This was not the students' first exposure to model construction. Many have been exposed to modeling in art classes, and all students participated in a modeling project earlier in the year.

The Activity of Rapid Prototyping

The case study consists of two sections of the same course. Both sections were taught in the same classroom with a nearly identical curriculum. Deanne Olsen's class had 25 students with three male students. Susan Tibbitt's class had 21 female students and no male students. The difference in class enrollment is considered to be due to the time when the courses are taught and not due to the instructors' reputation. Observations began with activities leading into the chair design. Students in both courses appeared slow to react to activities and exhibited a minimal level of enthusiasm.

When the introductory presentation to rapid prototyping is given, this low level of enthusiasm is continued. Leading questions are asked if students are familiar with rapid prototyping or three dimensional printing. Only one student in one class claims to have heard of it and what it does. Through several attempts to explain how the machine works and what it does, it is clear that the students do not fully grasp the concept and any understanding is abstract at best. After the brief introduction, the class walked across campus to the rapid prototyping lab. At this point the enthusiasm exhibited from both classes remained less than anticipated.

Upon arriving at the lab and being able to see the rapid prototyper in action and examples of printed parts, the students' enthusiasm increased. The students began asking questions about exactly how the machine worked, what the limitations were, and what they could do and what they had to do in order to use the machine. After the classes were dismissed by the instructor, several students from both classes remain for several minutes to ask additional questions and handle the printed models. Both instructors stated that the students seemed very excited to use the rapid prototyper.

As a participant observer, and as the only person in the study with rapid prototyping experience, the author attended both classes throughout the project. Students typically had questions on what was printable and the projected cost. Even after design guidelines were presented such as minimal size, and file type and characteristics, students still wanted reassuring feedback if their design would print.

Students completed their designs using AutoCAD software. The designs were ready to print as early as two days after completion of the rough outline of their design. After this rough outline was conceived, the students had ten days to complete the final model. A steady stream of students printed the models beginning eight days before the model was due. All models except two were finished printing two days before the due date. One of the unprinted models resulted from file conversion difficulties. The student redrew the model and it was printed the following day. The other appeared to be due to procrastination. The process ran smoothly with only one model failing to print correctly on its first iteration.

CHAPTER V

DISCUSSION

Subproblem #1

Subproblem #1 stated, "Do students receive the same quality and quantity of feedback to improve their designs from each method? If students do not receive the same quality and quantity of design feedback, what is the nature of the difference?"

The first research question addresses whether students receive the same quality and quantity of feedback through the design process to improve their design in rapid prototyping. The analysis of this research question has been divided into two subparts based on the feedback sources. These sources are described as interpersonal and intrapersonal feedback.

Intrapersonal Feedback

Preliminary models, final models, and 3D CAD modeling represent the design revision and feedback stages of the project. Any claim that rapid prototyping produced a different quantity of feedback should be displayed in these stages of the design process (Howard, Culley, & Dekonick, 2008; Renshaw, 2002). Cross tabulations of rapid prototyping versus the question "the following tools have influenced my design greatly:" yielded highly nonsignificant results in the areas of preliminary models ($p < .458$), final models ($p < .727$), and 3D CAD modeling ($p < .605$). Graphical representations of the data show no inference or trend.

The students were asked to agree or disagree with the statement "overall, I feel the quality of my design has improved throughout the project." All except two students agreed or strongly agreed with the statement. In a comparison, students who used rapid prototyping showed no significant ($p < .387$) difference in design improvement throughout the project than students who constructed their models by hand. The data are displayed in Table 37.

Additional data collected from open-ended survey question "what was the most positive aspect of the project" yielded six responses coded as the design process. Four of the six students responded that the design process was the most positive aspect of the project built their model by hand versus two who used rapid prototyping. This ratio is aligned with the ratio of hand-built models to rapid prototyped model further suggesting little or no difference in design feedback. This data suggests rapid prototyped models do not differ from hand constructed models in provide the same level of intrapersonal design feedback.

Interpersonal Feedback

Interpersonal feedback was approached from the tools and methods used in communication between persons. Preliminary models, final models, and 3D CAD modeling represent the design revision and feedback stages of the project. Any claim that

Table 37

Overall, I Feel the Quality of My Design Has Improved Throughout the Project

Professional use	Strongly agree	Agree	Disagree	Strongly disagree
Rapid prototyping	1	5	0	1
Hand construction	4	7	1	0

rapid prototyping produced a different quantity of feedback should be displayed in these stages of the design process. Cross tabulations of rapid prototyping versus the question "the following tools were effective in sharing information and ideas with other people." yielded nonsignificant results in the areas of final models ($p < .594$); and 3D CAD modeling ($p < .348$). Likewise, graphical representations of the data show no inference or trend. Preliminary models were built by an insufficient number of rapid prototyping students (2) to receive data with statistical power.

Summary

No conclusive evidence is given to suggest that rapid prototyping differed from traditional hand construction in the quantity and quality of intrapersonal and interpersonal design feedback throughout the project. No articles were found through a search of literature (Chapter II) addressing the effects of rapid prototyping on the design process. Observations showed few students revising designs and models after the initial design stages, which is consistently considered an important part of the design process (Alley, 1961; Frampton & Kolbowski, 1981; Janke, 1968; Kelley, 2001; Renshaw, 2002; Starkey, 2006). The initial design stage was considered concluded on the day the instructors' due date for preliminary sketches. This breakdown of design reiterations following the initial design stages was considered by the instructors to be due to limited time for the project.

Subproblem #2

Subproblem #2 stated, "Is the quality of the finished presentation models the same for each method? If the quality of the presentation models is different, what is the nature of the difference?"

An important aspect in any analysis of model and prototype comparison is the quality of the model. According to many case study articles, it seems intuitive that rapid prototyping produces a finer model than hand constructed techniques. Many articles have claimed the rapid prototype produced models produces finer models but lack valid data supporting such a claim (Bohn, 1997; Flowers, 2002; Gibson et al., 2002; Iwamoto, 2004). See Table 1 summary of related articles in rapid prototyping and architectural education for a reference of those claims.

The first area to be assessed is the area of rapid prototyping and the effects on scale within a model. The mean score given by the evaluators for scale compared between the rapid prototyping and the traditional hand built models shows significance ($p < .03$) in an independent sample t test with a difference of means being 1.27 on a scale of ten. Not only was the mean greater among the rapid prototyping group, but the variance of scale was reduced as well (4.22 vs. 2.00). This is show in Table 38.

The second area to be assessed is of rapid prototyping and the effects on construction quality within the model. The quality of craftsmanship shows to be

Table 38

Comparison of Rapid Prototyping Versus Hand Construction on Scale

Method used	Mean	*SD*	Std. error of the mean
Hand construction	7.70	2.05	.41
Rapid prototyping	8.97	1.41	.37

statistically significantly ($p < .027$) better by a factor of 1.38 on a scale of 10. Similarly to scale, the variance within the craftsmanship was less with the rapid prototyping group (4.66 vs. 2.38). This is show in Table 39.

Due to the variable nature of design subjectivity, all evaluators will be analyzed separately. The mean comparison (Table 40) shows a difference in means between rapid prototyping and tradition construction methods, but none show significance in the independent sample t test due to insufficient sample size. P-values for each evaluator are as follows: (Evaluator 1 = $p < .199$; Evaluator 2 = $p < .729$; Evaluator 3 = $p < .276$).

Table 39

Comparison of Rapid Prototyping Versus Hand Construction on Craftsmanship

Method used	Mean	*SD*	Std. error of the mean
Hand construction	7.02	2.16	0.43
Rapid Prototyping	8.40	1.55	0.41

Table 40

Comparison of Rapid Prototyping Versus Hand Construction on Design by Individual Evaluators

Evaluator	Method used	Mean	*SD*	Std. error of the mean
Evaluator 1	Hand construction	7.98	3.206	.716
	Rapid prototyping	9.69	4.309	1.195
Evaluator 2	Hand construction	12.64	4.337	.924
	Rapid prototyping	13.15	4.064	1.127
Evaluator 3	Hand construction	12.40	3.239	.976
	Rapid prototyping	13.94	2.766	.922

A shift of four units was applied to the scores given by evaluator 1 to gain interobserver reliability. See results for a description of the shift and interobserver reliability tests. The overall mean of the students design score with the shift was compared for differences by rapid prototyping. A difference of approximately one unit out of 15 units was exhibited with a nonsignificant *p* value ($p < .345$) in an independent sample *t* test (Table 41).

Before analyzing the total score (sum of design, scale, and craftsmanship) for the project, it was noted that mean scores of rapid prototyping projects were higher in all three areas than mean scores of hand-built projects. As expected from the data above, the mean value of the total score was higher (3.85 units out of a total of 35) and yielded a slightly nonsignificant *p* value ($p < .081$) on an independent sample *t* test (Table 42).

Table 41

Comparison of Rapid Prototyping Versus Hand Construction on Design by Mean of Evaluators

Method used	Mean	*SD*	Std. error of the mean
Hand construction	12.10	3.157	.631
Rapid prototyping	13.09	3.009	.825

Table 42

Comparison of Rapid Prototyping Versus Hand Construction on Total Score by Mean of Evaluators

Method used	Mean	*SD*	Std. error of the mean
Hand construction	26.61	6.770	1.354
Rapid prototyping	30.46	5.742	1.534

Summary

In all categories, the mean score of students using rapid prototyping was greater than the mean score of students using traditional had techniques. The greatest areas of difference were found in scale and craftsmanship. This was expected in the literature (Bohn, 1997; Flowers, 2002; Gibson et al., 2002; Iwamoto, 2004) and was expected in the study. The large effect size of the difference in scale ($d = .68$) and craftsmanship ($d = .70$) carried over into the total score ($d = .60$).

A difference was found in design, but lacks statistical significance. A test of effect size ($d = .32$) yields a small to medium effect size which would be too small to detect significance in the sample size. A sample size greater than 50 per group would be required to give the power necessary to avoid a type II error with a small effect size (Moore & McCabe, 2006). The data suggests that further exploration is needed to identify if rapid prototyping does have a small to medium effect. This area was not addressed within the literature and is an expectation of the instructors.

Subproblem #3

Subproblem #3 states, “Do students enjoy, appreciate, value, or experience the same frustrations from each method of model construction? If students differ in affective dispositions, what is the nature of the difference?”

Enjoyment

Students were asked to assign a level of agreement to the statement “I enjoyed doing the following: preliminary sketches, preliminary model, final model, 2D CAD, 3D

CAD, 2D hand drawings, and 3D hand drawings." The level of agreement varied between the activities and students were not required to complete all activities with the project. The answers reported for enjoyment of the various tasks was analyzed against the method the students used to create their final model. The findings showed no visual patterns in any cross tabulation and all factor yielded nonsignificant *p* values with a Pearson chi-square test. *P* values for the individual activities are as follows: preliminary sketches ($p < .116$), preliminary model ($p < .388$), final model ($p < .566$), 2D CAD ($p < .446$), 3D CAD ($p < .431$), 2D hand drawings ($p < .610$), and 3D hand drawings ($p < .405$). The influence of rapid prototyping could not have an effect on students in the preliminary sketching stage as the random selection of students to rapid prototyping or tradition construction did not occur until after the preliminary sketching activity.

Frustration

Students were asked to assign a level of agreement to the statement "I was frustrated doing the following: preliminary sketches, preliminary model, final model, 2D CAD, 3D CAD, 2D hand drawings, and 3D hand drawings." The level of agreement varied between the activities and students were not required to complete all activities with the project. The answers reported for frustration of the various tasks was analyzed against the method the students used to create their final model. The findings showed no visual patterns in any cross tabulation and yielded nonsignificant *p* values with a Pearson chi-square test for the following activities: preliminary sketches ($p < .276$), preliminary model ($p < .687$), 2D hand drawings ($p < .342$), and 3D hand drawings ($p < .347$).

The activities in the design process expected to be affected most by rapid prototyping showed visual patterns or statistical significant differences between rapid prototyping and traditional hand construction. These areas include: final model, 2D and 3D CAD drawings. Final models (Table 43) showed no statistical significance ($p < .272$), but displayed a pattern of interest in that five students reported agreeing or strongly agreeing to experiencing frustration in creating the final model by hand versus one student who agreed to experiencing frustration from the rapid prototyping group. This response is consistent with the views on rapid prototyping the available literature on the subject.

Statistical significance was found in the cross tabulation of both 2D CAD drawings ($p < .044$) and 3D CAD drawings ($p < .048$) against the method used for final model construction. This data states (Table 44 and Table 45) that students who used rapid prototyping experienced a higher degree of frustration in CAD design versus students who used traditional hand construction. This can be theorized as the usage of CAD as exploratory data for shape and form for both groups with the rapid prototyping group being required to fine tune the design to precise and accurate final dimensions (Gibson et al., 2002; Gross, 1994).

The data show that the use of rapid prototyping did not remove frustration from the project, but rather shifted frustration from the physical model construction to the

Table 43

Response to the Statement: I was Frustrated in Creating A Finished Model

Method used	Strongly agree	Agree	Disagree	Strongly disagree
Hand built	2	3	2	5
Rapid prototyping	0	1	4	2

Table 44

Response to the Statement: I was Frustrated in Creating 2D CAD Drawings

Method used	Strongly agree	Agree	Disagree	Strongly disagree
Hand built	0	0	2	4
Rapid prototyping	0	2	3	0

Table 45

Response to the Statement: I was Frustrated in Creating 3D CAD Drawings

Method used	Strongly agree	Agree	Disagree	Strongly disagree
Hand built	0	0	4	4
Rapid prototyping	1	3	3	0

virtual (CAD) model construction. It must be noted that the parameters of the experiment did not require the use of CAD drawings in the project. 3D CAD drawings were required in finished detail for students using rapid prototyping as an inherent process to rapid prototyping. Students who constructed their models using hand techniques were allowed, but not required to use CAD as a tool and varied in detail, accuracy, and precision.

Value

Students were asked to assign a level of agreement to the statement "As a student learning about design, I find the following to be valuable: preliminary sketches, preliminary model, final model, 2D CAD, 3D CAD, 2D hand drawings, and 3D hand drawings." The answers reported for valuing the various tasks was analyzed against the method the students used to create their final model. The findings showed no visual patterns in any cross tabulation and all factor yielded nonsignificant *p* values with a

Pearson chi-square test with all activities except final models. The *p* values for the individual activities are as follows: preliminary sketches ($p < .581$), preliminary model ($p < .652$), 2D CAD ($p < .707$), 3D CAD ($p < .363$), and 2D and 3D hand drawings ($p < .515$). Value for final model construction versus method used yielded a slightly nonsignificant *p* value ($p < .110$), and showed high value for both students using either method. It is unclear how the data will appear with a greater data set. Table 46 of value for final model construction versus method used is given below.

Professional Use

Students were asked to assign a level of agreement to the statement "If I were faced with a similar design project as a professional after graduation, I would likely create a: preliminary sketches, preliminary model, final model, 2D CAD, 3D CAD, 2D hand drawings, and 3D hand drawings." The question was designed as an alternative method of asking for value placed on the various design tools. The findings showed no visual patterns in any cross tabulation and all factor yielded nonsignificant *p* values with a Pearson chi-square test with all activities except final models. The *p* values for the individual activities are as follows: preliminary sketches ($p < .605$), preliminary model

Table 46

Response to the Statement: As a Student Learning about Design, I Find Final Models to be Valuable

Method used	Strongly agree	Agree	Disagree	Strongly disagree
Hand built	7	4	0	0
Rapid prototyping	6	0	0	1

($p < .557$), final model ($p < .829$), 2D CAD ($p < .382$), 3D CAD ($p < .581$), 2D hand drawings ($p < .126$), and 3D hand drawings ($p < .630$).

Probable professional use versus 2D hand drawings yielded a slightly nonsignificant *p* value ($p < .126$), and showed a weak visual patterns that may prove significance with greater power in the test. This shows no consistency with students' value placed on 2D hand drawing. As a check for consistency in value, probable use as a professional was analyzed against method used and showed almost no variation in response given a stronger argument for there being no correlation between method used and value for final models.

Summary

It was interesting to note that no area exhibited correlation between frustration and enjoyment in the project, which presents an area with future research potential. This correlation was considered intuitive by the researcher and from within the literature (Daniels et al., 2008; Pekrun, 2006). No strong argument was presented for a difference in value or probable professional use with individual design tools use between rapid prototyping and traditional hand built techniques. The evidence shows a possibility of the concentration of frustration being shifted by rapid prototyping from construction of the final model to the development of accurate CAD models and not removing the frustration as was anticipated by the research and several articles (Flowers, 2002; Giannatsis et al., 2002; Tennyson & Krueger 2001). This proposal that frustration within the project is shifted needs greater investigation to strongly suggest its existence. As with the majority of the survey, a greater sample size would increase the statistical power and plausible inference presented therein.

Subproblem #4

Subproblem #4 stated, “Are the investments of money and time comparable from the students within the project for each method? If the investments are different, what are those differences?”

The aspects of time and monetary investments are an area of concern for professional designers. The advantage of studying these factors in an educational setting is being able to control for factors such as design requirements and clientele differences, which would exist in a professional setting. A major criticism of design education is its separation from office realities, addressing the issues of time and monetary investments seems reasonable in an education setting (Mitgang, 1999). Likewise, activities that require more time limit coverable subject matter in a curriculum.

Time

Time invested into a project is of interest to an educator because time is a limited resource and will affect the depth and coverage of all topics in a curriculum. Students were asked to record the time spent on critical aspects of the design process. These aspects were plotted against rapid prototyping and tradition construction techniques. The mean values of these categories are given in Table 47.

The difference in mean time spent appears greater than the statistical significance test between groups. This is impacted in two parts. One being a large variance in the mean values and a small sample size. As the sample size increases, the statistical power

Table 47

Descriptive Statistics for Time Invested

Variable	Method used	Mean	*SD*	Std. error of the mean
Sketching/visualization	Hand construction	3.3	2.2	.49
($p < .149$)	Rapid prototyping	1.9	1.2	.35
Final model	Hand construction	2.9	2.5	.56
($p < .156$)	Rapid prototyping	4.1	2.5	.72
3D cad	Hand construction	5.8	2.8	.63
($p < .349$)	Rapid prototyping	3.6	3.7	1.07
Total time invested	Hand construction	11.1	4.9	1.10
($p < .358$)	Rapid prototyping	8.9	5.5	1.59

increases and the likeliness that a factor will show significance in the case that a correlation exists thus avoiding a type 2 error. The ANOVA for time factors contrasted by the variable of method used is given below.

Cost

Cost is an area of interest on this project not only from the professional standpoint, but also due logistical and ethical issues associated with an education program. Examples of these issues are how a department would collect larger sums of money from students and requiring students to utilize the equipment with a large expense attached in order to receive a good grade. Two aspects of model construction showed expenses in the project. Those two aspects were materials and tools. Tool expenses were greater for traditional construction methods and occurred in less than 10% of the data. Materials were a greater expense for rapid prototyping students. Overall, rapid prototyping students incurred a greater cost in the project. The mean values of areas of cost in the project and any analysis of variance between cost and method used is given in Table 48.

Summary

A strong difference is shown the cost of the projects with rapid prototyping being more expensive to the students than hand built methods and was consistent with the literature (De Beer et al., 2004; Dimitrov et al., 2006; Giannatsis et al., 2002; Gibson et al., 2002; Ryder et al., 2002; Tennyson & Krueger, 2001).

However, there appears to be a difference in time required for the project that may show apparent with a larger sample size to avoid a type II error. It was anticipated that this difference exists (Bohn, 1997; De Beer et al., 2004; Dimitrov et al., 2006; Giannatsis et al., 2002; Gibson et al., 2002; Ryder et al., 2002) The data also suggests a shift in student time from sketching and conceptualizing to 3D modeling for students using a rapid prototyping process. As stated before, a larger sample size is needed to support this initial data, and further research should be conducted in the presence of this shift as to the effects it will have on the design process.

Table 48

Descriptive Statistics for Money Invested

Variable	Method used	Mean	*SD*	Std. Error of the mean
Materials ($p < .022$)	Hand construction	14.04	9.29	2.39
	Rapid prototyping	35.85	17.29	4.99
Total money invested ($p < .023$)	Hand construction	16.21	13.47	3.48
	Rapid prototyping	40.68	17.73	5.12

A judgment of invested value (Table 49) is derived by giving a value to time of $10.00 an hour as determined to be an approximate wage of an intern in the design field. With the variable of invested value, there was virtually no difference between rapid prototyping and hand built construction. This is in contrast to several articles stating that rapid prototyping would be far too expensive for most architectural and design firms (De Beer et al., 2004; Giannatsis et al., 2002; Wai, 2001).

Subproblem #5

Subproblem #5 stated, “Does the availability of technology limit or enhance the design complexity? If the technology impacts the design capabilities, in which ways, and how great is this effect?”

In the experiment, students were introduced to rapid prototyping and the random selection of students into the rapid prototyping was explained. Students began designing without knowledge of which group they would be selected to. Selection occurred after students had finished preliminary sketches and ideas. Did this selection change the students designs?

In interviewing the instructors, a concern was stated that requiring students to

Table 49

Descriptive Statistics for Total Value Invested

Variable	Method used	Mean	*SD*	Std. error of the mean
Total money invested ($p < .967$)	Hand construction	155.38	48.70	19.86
	Rapid prototyping	153.60	90.85	37.08

create a model would limit students as to what could be constructed by the means available. Observations showed that students tended to stay with their original design idea even when they were difficult to construct. This is discussed fully in subproblem #6 under the subheading “opening possibilities for design.”

The survey addressed this issue by asking the students a series of three questions. The first two questions ask the students “I would consider my design difficult to build by hand” (Table 50) and “I would consider my design difficult to build by using a rapid prototyping process” (Table 51). A Pearson chi-square test showed nominally nonsignificance ($p < .105$) with the low level of statistical power in the test. A verbal analysis can describe the difference better. A majority of students (63%) disagreed or strongly disagreed with their design being difficult to build using a rapid prototyping method, whereas a majority of students (68%) agreed or strongly agreed with their design being difficult to build by hand.

This infers that students perceive hand built models to be more difficult to build than rapid prototyped models. There was no correlation when coded for rapid prototyping

Table 50

I Would Consider My Design Difficult to Build Using a Rapid Prototyping Process

Response	Percent
Strongly agree	10.5
Agree	26.3
Disagree	21.1
Strongly disagree	42.1

Table 51

I Would Consider My Design Difficult to Build Using a Hand Construction Process

Response	Percent
Strongly agree	31.6
Agree	36.8
Disagree	31.6
Strongly disagree	0

versus hand built models inferring the perception to be uniform regardless of the method used by the students. Contrary to the observed data that students' designs did not change or alter due to the method assigned to them after the design was conceptualized, the majority of students (69%) agreed or strongly agreed that their method of construction influenced their design. Table 52 shows student responses. There was no correlation ($p < .784$) when rapid prototyping was compared against hand built models.

Summary

Students perceived hand built models to be more difficult than rapid prototyped models. With two of three grading criteria (craftsmanship and scale) linked directly to model quality, one would hypothesize that some students would modify their designs if accuracy would be difficult to achieve in a nonrectilinear or organic design. The students responded that the construction method selection or the availability of rapid prototyping influenced their designs. Several articles suggest rapid prototyping to allow for more complex prints, but do not explicitly state student will modify their design according to

Table 52

The Method of Construction Assigned to Me (Hand Built or Rapid Prototyped) Influenced My Design

Response	Percent
Strongly agree	21.1
Agree	47.4
Disagree	26.3
Strongly disagree	5.3

available technology (Dimitrov et al., 2006; Gibson et al., 2002; Tennyson & Krueger 2001). In contrast to the survey data, observations showed that many students carried through with their original design after not being randomly selected for rapid prototyping use.

Subproblem #6

Subproblem #6 states, "What are the expectations and potential of rapid prototyping from the perspective of the instructors in the study, and how do expectations contrast to the observed events?"

This case study is designed to give the interested educator the experience of implementing rapid prototyping without the time and financial risk. As Stake (1995) pointed out, we are interested in case studies for both their uniqueness and commonality. To fully understand the case study, an appropriate awareness of the program setting and goals is requisite. This was given in Chapter IV. Likewise, an observation description of the case was given in Chapter IV due to the relevance in understanding and applying data from this case to any other.

The case study focused on the instructors' perspectives of the activity. Although there are two instructors teaching two distinct sections of the same course, their expectations were congruent on most facets. Therefore, the perspectives have been synthesized into a singular expectation with differences in the individual expectations being noted.

The main research question states, how does the implementation of a rapid prototyping activity compare to the instructor expectations? A synthesis of researcher and instructor observations will then address this critical question and the bulk of the purpose of the study.

Rapid Prototyping to Improve Communication

One of the most difficult tasks in design is clearly communicating what one person sees in their head. According to one instructor, the strongest effect expected would be that of improving the communication potential for the assignment and program. This communication breakdown resulted in the difficulties in transferring the image and design which lies in the student's head and constructing an appropriate representation. The rapid prototyper will be useful in bridging the gap created by dexterity and construction skills developed through experience which the students may not have, and what exists in the conscious of the students. The instructor Susan Tibbitts shared her insights:

> I hope that they will be better able to communicate their ideas. Because I know that they know what it looks like in their head, and to them it's perfect, and every time they try to build a model it doesn't come out right—unless we have some fantastic model builders, which are few. And so, they will have some amazing

> ideas, and they literally don't show. They don't come off across as well as they need to. And we can go ahead and in our heads try to make the connections of what it should have been from what it actually looks like. I am hoping that this will take care of a lot of those issues, we'll have a lot better models, and more of them that look really good, and just communicate well…. So if you have a bad idea, and you carry it out, and your models bad and everything is bad, and you then have this horrible project that you wish would die. I don't know if there is really a way of changing that, but there may be a better result of this that makes them more pleased with their own work.

The observations showed students were very pleased with the outcome of their models. Rapid prototyping has shown to be a strong tool bridging the information and communication gap between design originator and audience. The quality of the printed models was exceptional, and both students and instructor were very pleased with the outcome.

Creating Possibilities for Students with Limited Exposure to Model Construction

With the high expectations for quality and precision, the assignment to construct a model can be considered a daunting task, as made clear by one instructor. Susan stated:

> Those who don't build models well, hate building models. They dread it. They have done their tiny house, which they built with foam core and kind of understand foam core now. Now they are asked to deal with all these various materials that they don't know how to deal with, and they don't have a lot of time or room for error.

> Students who used rapid prototyping displayed no hesitancy in their design to model activities. As was anticipated, several students asked questions as to the limits and possibilities of the rapid prototyper. Several students, which came as no surprise to the instructors, created designs that would require themselves to use the rapid prototyper to realistically create. These designs exhibited a stronger sense of organic designs.

Opening Possibilities for Design

One instructor pointed out a trend for designs to be modified as the assignment has proceeded in the past. This trend starts out with design being wide open and students responding with in intricate, creative, organic, and exploratory shapes and designs. As the reality of constructing a model approaches, the students simplify their designs out of lack of experience with difficult designs, and the difficulties that may inhibit them from achieving their objective. Instructor Deanne Olsen pointed out:

> When they first start designing, it's wide open, and they come up with some really clever designs, but when they start building a model and looking at how it is going to be constructed, they start to back off to designs with straight lines.

This idea of a filter restricting designs is shown in Figure 8.

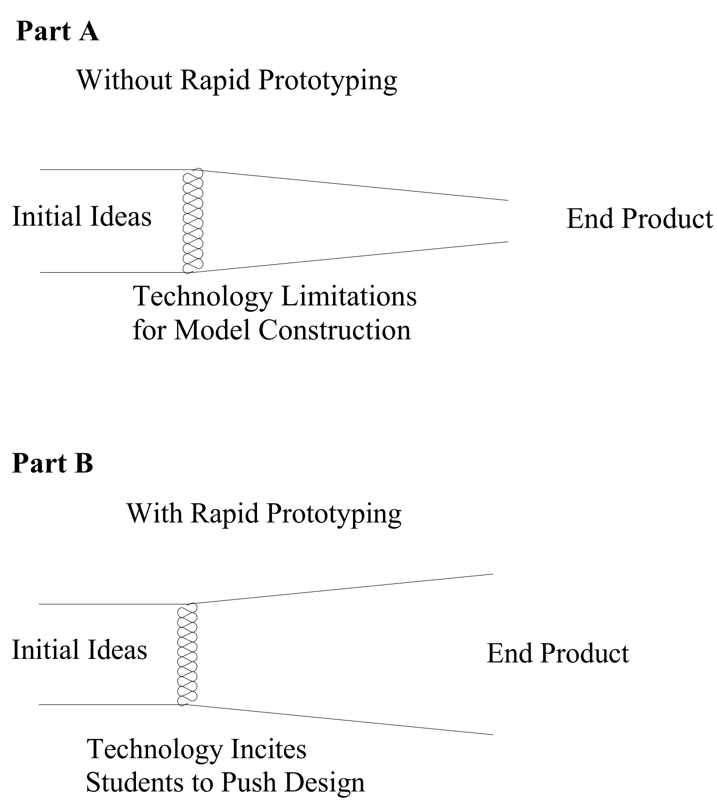

Figure 8. Visual representation of the instructors' expectations of technological impacts on design. Part A represents the expectation or assumption that a filter limits what students can do in the assignment according their skills in constructing models by hand. Part B represents the expectation or assumption that an amplifier excites what students can do in the assignment by testing what new technology (rapid prototyping) can do.

The expectation stated by both instructors was that not only will this filter be removed, but will be replaced by a magnifier. This magnifier can be seen as a challenge presented to the students to test the capabilities of the new technology. By presenting cutting edge technology to the students, the response may be to push designs beyond what may have been present without the availability of rapid prototyping. Susan stated:

> Those who may lean toward the more contemporary or modern funky things may lean more towards the rapid prototyper. I think there may be some who set out to use the rapid prototyper. I think some may be pumping us and say, ok, what do you think can be built on the rapid prototyper?

Deanne added to this idea, "I think that is one of the things that I am most excited for, is to see how they will challenge it—especially the ones that are not afraid of technology." Similarly, a visual representation is given to this idea above.

Rapid Prototyping and the Effects on Student Populations

It is clear that technology will affect students differently, the question is simply which students will be most impacted and how will it affect them. The simplest and obvious answer was students and their level of technical inclination. It was considered intuitive that students with an aptitude and enjoyment for new technology would embrace rapid prototyping, while students who struggle more and are less familiar with technology will face more difficulties in rapid prototyping. The question lies in what indicator will identify students.

In this case, a strong indicator may be in what attracted students to the program. Many students are attracted to interior design through their exposure to interior decorating. This exposure can come in many forms, with the most common being television programs. Students who enter the program with this expectation of interior decorating and less exposure to the other aspects of interior design may resist or struggle more in the technical aspects of the activity. Deanne Olsen pointed out:

> I think it depends on how our students came into the program. If they watched a lot of television shows like HGTV and were more interested in the decorating, I think the technology will be a little more frightening to think that they actually have to do this design. I think that design is fascinating because with design you have to incorporate the artistic portion, innovation, and construction. I think that when they realize that it seems like a lot.

Along similar lines, the ability to design with 3D CAD programs, the strength of design skills, and comfort with design and in taking a risk in design will play into the performance of students when faced with rapid prototyping. Susan Tibbitts pointed out:

> The pressure is going to be that they have to be awesome at 3D, and hopefully, there are always those that are, and they are going to be well prepared, and then there are going to be those who don't get it. They are going to have a hard time building it and getting it to be really what they want it to be. Students who perform best will probably be those who feel comfortable with CAD, and feel comfortable with their design skills, because they are more comfortable with those aspects, they will be more comfortable in taking a risk, and go out on a limb and try something new, more than someone who is not as confident with those other things. That's my guess of who will be more successful with this whole process.

Synthesizing the two perspectives suggests: students who are better prepared for the design program, more experienced in aspects of the design program, and naturally better designers will have better success with an activity involving rapid prototyping. In the case of a program, which must differentiate between the top third of their students able to continue on in the studio emphasis, this is not necessarily a negative trait. This is not to state that the instructors concentrate on the best students only, the instructors care about the success of all students, but is intended to state that the activity can serve as an indicator of students' abilities to succeed in the rigorous studio track program.

No clear distinction was made on students choosing or showing hesitancy to use rapid prototyping, when the materials fit their design appropriately. Nearly all students in both classes showed interest in using the technology. This may be due largely to the ease of use that the machine presents to the students. The effect of rapid prototyping on the students was noticeable to both instructors as well as the researcher. Students with a higher aptitude for design seemed to breeze through the design and the products emerged with a strong sense of clean, proportional design.

Models will be Adjusted up to the Due Date, and Students Will Procrastinate to the Final Moments of the Project

This expectation stems from prior experience with the students in this project and other projects. The fear that these traits from previous activities are that rapid prototyping has a limited capability for production. It was estimated that one rapid prototype machine could produce six models per day. This would result in a bottleneck with 20 students trying to print in a 2-day window with a deadline looming on the horizon. Although the students are scheduled to have approximately 9 days from having a design to a completed model, the expectation still lies at the majority waiting until the last few days. The instructors exhibit a strong sense of adaptability to needs as they arise.

This expectation appeared to be the largest misconception of the case study. The researcher as well as the instructors fully expected a bottleneck and frantic rush to produce the models in the last 2-3 days of the assignment with several models not being printed until after the due date due to the capabilities of the printer. As stated previously, all of the models with a few exceptions were printed a full 48 hours before the deadline.

The students began to print the models sooner than expected, and did so in an orderly manner. The instructors expected that pressuring the students to print their models early would be required for the project to succeed which proved not to be necessary for the case. In comparison to previous years and students who built their models without rapid prototyping, most models were not completed until the final days of the assignment with several models not being completed until after the due date.

No adjustments i.e. reprinting of the models was done after being initially printed even those with clear design flaws and incorrect proportions. This has been noted in model construction that students are hesitant to revise models once they are constructed (Alley, 1961; Denzin & Yvonna, 1998; Frampton & Kolbowski, 1981). Through the study it was clear that students were conscientious of the cost of the prototypes with the average and median cost being between $32 and $33.

Students Will Look to Rapid Prototyping to Correct Design Flaws

Deanne Stated, “The students may see the machine as magic, and they can cut corners on the design and the machine can build everything for them. They won’t be as diligent on the design, the scale, or the construction methods.” This attitude would be detrimental to the activity if the attitude exists. If this were to occur, the outcome would have an adverse effect on the program and the educational objectives. The activity is designed to teach the analytical aspects of design. If this concern surfaces during the project, this may result in an expectation for technology to compensate for poor design.

This insightful expectation displayed the major shortcoming of the implementation of rapid prototyping showed to be an area of concern to be taken seriously for future projects with the rapid prototyper. Several CAD drawings were not examined as closely as they should have been and many contained design flaws that carried over into the printed model. Common flaws included the following.

1. Incomplete transitions from one part of the model to another which resulted poor joining of parts. This was common in parts that were assembled as separate solids in CAD such as chair legs, back supports, and chair arms.

2. Proportional and strength related issues that would also surface in hand built models. These issues are addressable as a CAD model, but are more readily corrected during the creation of a hand built physical model.

3. Expectation that detail printed by a rapid prototyper prevail over design. The impressive accuracy and detail inherent to rapid prototyping cannot supersede the need for good design principals and theory.

Additional Observations

The level of enthusiasm exhibited by the students exceeded the expectations of the researcher and the instructors. This enthusiasm was easily displayed in how the students reacted in completing the project early, the demeanor upon seeing the projects that have been printed, the amount and types of questions posed, and in seeing their own designs come to life.

Additionally, the instructors noted how smoothly the project flowed. This surprise was in part due to expecting a new dimension being added to the curriculum may require some troubleshooting and in the relief of discussing and revising difficult construction materials and methods. The project has been successful in the past, but has always had a strong sense of adaptation and troubleshooting.

Summary

As stated above, the task of making connections from this case study to other possible cases is best done by one intimate with the program considering using rapid prototyping. The rapid prototyper will be used in additional projects for students continuing on through the studio track and will continue to enrich the projects for years to come. Several concerns such as design analysis will be a change in the focus in succeeding projects and courses. A strong measure will be in analyzing how the technology will impact the curriculum over time. As the instructors become better acquainted with the process, and as students have examples from past students to build from, what direction will the project take in the future? Will the project become known as "the rapid prototyping project" and hand built models not being a consideration for projects better suited to that method?

Summary, Conclusions, and Recommendations

One focus of this study is to identify trends and data into the emerging use of rapid prototyping. This section will discuss key trends identified from the study and areas which need to be further investigated.

The quasi-experimental nature of this study showed a common weakness in design programs. This weakness is in the linear nature of the assignment, where students do not revise their project after a first prototype. This study would suggest that rapid prototyping in the natural application presented did not teach the iterative nature of design better than the hand built models. With respect to technological literacy, this component of design education did not lead to a better understanding of design standards (standards 8, 10, and 11) in the standards for technological literacy. In this case, time constraints prohibited design revisions being a part of the curriculum.

Research should be conducted into the possibility of rapid prototyping encouraging a singular, linear design model. Causes of this model may be attributed to increased cost for each prototype/model in rapid prototyping, or a hesitancy to continue past the initial prototype as is common in education.

No data collected suggested that rapid prototyping had an effect on the ability to communicate design ideas between people. The study therefore shows no evidence that rapid prototyping will result in a deeper or broader understanding of any of the standards for technological literacy than would exist in a hand built prototypes is a design curriculum.

As was assumed by the instructors and from within the literature, rapid prototyping produced finer models in terms of craftsmanship and scale. Additional to mean scores on these two aspects being higher, the variance of the rapid prototyping group was approximately half that of the traditional hand-built method. As for design, all evaluators scored the design quality as being better for the rapid prototyped models versus the hand built models. There was no statistical significance, and a greater sample size would be needed to ensure avoiding a type II error. If a significance were to be found with a greater sample size as the preliminary data suggests there may be, then why would a model exhibit a stronger design in rapid prototyping than with traditional hand built models. Could this exist due to inherent processes in 3D CAD applications, magnified possibilities due to technologically created opportunities, or is this unique to this study? Additionally the question surfaces, are students actively reviewing and revising their design through CAD modeling while hand built models incorporates less design refinement?

The affective traits yielded a variety of data. No data showed any patterns of one method yielder a greater level of enjoyment as was anticipated by the instructors. Students experienced frustration in both methods but the frustration was exhibited in different areas. These areas were the critical areas of detail in the assignment with CAD being the frustrating task with the rapid prototyping group, and model construction being the most frustrating in the hand built model construction group. The data shows no significant difference in value for models or the likeliness one would use a model in a professional setting based on their experience with rapid prototyping or model construction. Likewise, no significance was shown for value for models when contrasted to the score that students received for their model. This may suggest that the aspect of value may be rooted deeper than a singular activity.

Cost was shown to be a significant difference between rapid prototyping and hand built models while time saved by rapid prototyping was not shown to be significant, but lacked the power necessary to be conclusive. Individual programs must evaluate whether the benefit greater than the cost of rapid prototyping, and further research will provide information to better accommodate decisions. As far as time is concerned, the time spent on certain aspects of the project changed with students spending more time in 3D CAD applications in rapid prototyping and students spending more time in sketching and conceptual phases outside of CAD usage, final model construction, and more time overall. The question to face educators and researchers is what affects will the task shifts have on the learning and understanding of design?

The instructors noted that their experience showed that rapid prototyping should open possibilities for design where hand built construction would limit those possibilities. This was stated to be true for more organic shapes. Likewise, the students stated that the method of model construction assigned to them had an influence on their design. The question did not probe what that effect was and if it open possibilities or not as is believed by the instructors. This was in contrast to observations that showed that students carried through with their design regardless of method assigned. With triangulation not pointing to a definite interpretation, many questions arise to be studied in the future. This lack of consistency by the methods does not show a lack of validity as triangulation is not a form of validity but is designed to provide rigor, depth, and breadth to any inquiry (Weiss, 1998). When multiple methods do not triangulate, the confidence of the researcher wanes on claims of the hypotheses. This is one such case that requires greater depth and breadth of research to better understand the effects of rapid prototyping.

Through qualitative measures, many aspects of rapid prototyping surfaced. This occurred as the qualitative measures were designed to provide exploratory data to be researched in depth in future studies. Aspects that surfaced included the following.

1. Rapid prototyping to be a stronger tool for technologically literate students than those with a lower level of technological literacy.

2. Rapid prototyping will improve communication.

3. Rapid prototyping will provide opportunities to students will limited model construction skills.

4. Students may look to rapid prototyping to correct design flaws.

All of these aspects could provide a basis for future studies into the claims previously made by instructors.

A final area to be explored is how rapid prototyping affects a design project with more time for revisions and follows a nonlinear model of design. What effects will rapid prototyping have on this model? If the craftsmanship and scale are improved with the first prototype, will the designer have a better platform with to modify the design in the future? Additionally, with rapid prototyping costing more than hand built models, will students be apprehensive to modify their designs as needed for financial reasons creating a wall the design revision process?

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APPENDICES

Appendix A

Survey

Model Construction

This survey is intended to better understand model construction in a classroom setting. While completing the survey is safe, you do not have to participate. Furthermore, you can stop participating at any time. Your name will not be published or used in the analysis, and will be destroyed after the study.

1. Demographics

[Top] [Section 1] [Section 2] [Section 3] [Submit]

1.1. What is your name?

1.2. What is your age group?

- 17 or less
- 18-19
- 20-21
- 22-23
- 24-25
- 26-27
- 28-29
- 30-34
- 35-39
- 40-44
- 45-49
- 50-54
- 55+

1.3. What is your class in terms of credit hours earned?

- Freshman
- Sophomore
- Junior
- Senior
- Graduate Student - Masters
- Graduate Student - Doctoral
- Other, Please Specify:

1.4. What is your gender?

- Female
- Male

1.5. What is your ethnicity?

- Hispanic
- African American
- Asian American or Pacific Islander
- White/ Caucasian
- Native American
- Mixed Racial
- International Student
- Other, Please Specify:

1.6. What is your intended major?

- Interior Design - Sales and Marketing
- Interior Design - Studio
- Other, Please Specify:

1.7. What is the highest level of education achieved by one of your parents?

- Some High School
- High School/ GED Diploma
- Some College
- College Graduate - Associates Degree
- College Graduate - Bachelor's Degree
- College Graduate - Graduate Degree
- Other, Please Specify:

2. Design Feedback

[Top] [Section 1] [Section 2] [Section 3] [Submit]

2.1. The following tools have influenced my design greatly:

	Did not use	Strongly Disagree	Disagree	Agree	Strongly Agree
a. Preliminary sketches	○	○	○	○	○
b. Preliminary model	○	○	○	○	○
c. Final model	○	○	○	○	○
d. 2D CAD drawing	○	○	○	○	○
e. 3D CAD model	○	○	○	○	○
f. 2D hand drawings	○	○	○	○	○
g. 3D hand drawings	○	○	○	○	○

2.2. The following people have influenced my design greatly:

	Did not use	Strongly Disagree	Disagree	Agree	Strongly Agree
a. Instructor	○	○	○	○	○
b. Other instructors in Interior Design	○	○	○	○	○
c. Students in Class	○	○	○	○	○

d. Other students in Interior Design	○	○	○	○	○
e. Other Students NOT in Interior Design	○	○	○	○	○
f. Family	○	○	○	○	○
g. Other	○	○	○	○	○

2.3. If you selected other, how would you describe your relationship to that person? Example co-worker, employer, boyfriend/ girlfriend, ect.

☐ Not Applicable

2.4. The following were effective in sharing information and ideas with other people:

	Did not use	Strongly Disagree	Disagree	Agree	Strongly Agree
a. Preliminary sketches	○	○	○	○	○
b. Preliminary model	○	○	○	○	○
c. Final model	○	○	○	○	○
d. 2D CAD drawing	○	○	○	○	○
e. 3D CAD model	○	○	○	○	○
f. 2D hand drawings	○	○	○	○	○
g. 3D hand drawings	○	○	○	○	○

2.5. Overall, I feel that the quality of my design has improved throughout the project.

○ Strongly Disagree

- Disagree
- Agree
- Strongly Agree

3. Interest and Attitude

[Top] [Section 1] [Section 2] [Section 3] [Submit]

Please answer the following with the answer that describes your experience best.

3.1. I enjoyed doing the following:

	Did not use	Strongly Disagree	Disagree	Agree	Strongly Agree
a. Preliminary sketches	○	○	○	○	○
b. Preliminary model	○	○	○	○	○
c. Final model	○	○	○	○	○
d. 2D CAD drawing	○	○	○	○	○
e. 3D CAD model	○	○	○	○	○
f. 2D hand drawings	○	○	○	○	○
g. 3D hand drawings	○	○	○	○	○

3.2. I was frustrated in doing the following:

	Did not use	Strongly Disagree	Disagree	Agree	Strongly Agree
a. Preliminary sketches	○	○	○	○	○
b. Preliminary model	○	○	○	○	○
c. Final model	○	○	○	○	○
d. 2D CAD drawing	○	○	○	○	○
e. 3D CAD model	○	○	○	○	○
f. 2D hand drawings	○	○	○	○	○

g. 3D hand drawings	○	○	○	○	○

3.3. If I were faced with a similar design project as a professional after graduation, I would likely create a:

	Strongly Disagree	Disagree	Agree	Strongly Agree
a. Preliminary sketch	○	○	○	○
b. Preliminary model	○	○	○	○
c. Final model	○	○	○	○
d. 2D CAD drawing	○	○	○	○
e. 3D CAD model	○	○	○	○
f. 2D hand drawings	○	○	○	○
g. 3D hand drawings	○	○	○	○

3.4. As a student learning about design, I find the following to be valuable:

	Strongly Disagree	Disagree	Agree	Strongly Agree
a. Preliminary Sketches	○	○	○	○
b. Simple Models (physical)	○	○	○	○
c. Detailed Models (physical)	○	○	○	○
d. 2D CAD drawings	○	○	○	○
e. 3D CAD drawings	○	○	○	○
f. Detailed hand drawing/ rendering	○	○	○	○

3.5. I would consider my design difficult to build by hand.

○ Strongly Disagree
○ Disagree

- Agree
- Strongly Agree

3.6. I would consider my design difficult to build using a Rapid Prototyping process.

- Strongly Disagree
- Disagree
- Agree
- Strongly Agree

3.7. The method of construction assigned to me (hand built or rapid prototyping) influenced my design.

- Strongly Disagree
- Disagree
- Agree
- Strongly Agree

3.8. What was the most positive part of creating a model?

3.9. What was the most negative part of creating a model?

Appendix B

Model Grading Rubric

Interior Design Chair Grading Rubric Name:

Area	Expectation	Does not meet high expectations of the program	3 minor discrepancies	2 minor discrepancies	one minor discrepancy	one minute discrepancy (only detectable by professional)	Meets all program expectations	exceeds program expectations
Grading Scale		0	0.5	1	1.5	1.75	2	2.5
Scale								
Internal scale consistent within model	all parts of the model are proportionate to each other							
Consistency to human scale	all parts of the model are proportionate to the human body							
Material proportionate to full scale representation	all materials proportionate to full scale i.e. wood grain, welds, stitching, upholstery patterns, ect.							
Model built to exact scale (1/2"=1')								
Professional Evaluator's opinion								
Subtotal								

Craftsmanship								
Area	Expectation	Does not meet high expectations of the program	3 minor discrepancies	2 minor discrepancies	one minor discrepancy	one minute discrepancy (only detectable by professional)	Meets all program expectations	exceeds program expectations
Grading Scale		0	0.5	1	1.5	1.75	2	2.5
Material appropriate to design	materials match the depiction of the design. i.e. wood looks like wood, metal like metal, ect.							
transition, internal consistency	materials are seamless, clean, and appear pristine							
Joinery	Joinery appear as it should and is appropriate to the model. Absolutely no excessive glue, screws, ect.							
Finish	Finish matches design intentions, appears smooth and clean							
Professional Evaluator's opinion								
Subtotal								

Design								
Area	Expectation	Does not meet high expectations of the program	3 minor discrepancies	2 minor discrepancies	one minor discrepancy	one minute discrepancy (only detectable by professional)	Meets all program expectations	exceeds program expectations
Grading Scale		0	1	1.5	2	2.5	3	4
Original / Creative	Project is student's own ideas							
Interesting	Project creates interest							
Professional	Project reflects the work of a professional designer							
Design principals	Project incorporates food design principals and is marketable							
Professional Evaluator's opinion								
Subtotal								

Appendix C

Assignment Outline and Time Schedule

ID2730 custom chair design

and magazine advertisement

ASSIGNMENT

Over the past week you have been working extremely hard to understand human dimensions and scale, ergonomics, anthropometrics, and how to apply all these concepts to create a practical design solution. You have the unique to be selected to use rapid prototyping technology or have access to the workshop in conjunction with the Engineering & Tech. Education Dept.
You will be responsible for all costs associated with making your model and ad.
Contact for model making: SCOTT GREENHALGH 435.590.7333

Now your challenge is to design your own CUSTOM CHAIR and ADVERTISEMENT.

REQUIREMENTS	DUE DATES
supplemental in class assignments	due in class
8" x 10" inspiration board	Monday, April 14th
4 magazine ads to evaluate	due in class
preliminary sketches that establish proper dimensions	Monday, April 14th
preliminary model	Wednesday, April 16th
preliminary ad	Friday, April 25th
a concept statement for your design	Friday, April 19th
drawings of your chair showing front, side top & back views with dimensions and one showing the human figure and how it relates to your chair	Wednesday, April 16th
a scaled model of your chair design 1 1/2" = 1'0"	Friday, April 25th
an 8.5" x 11" magazine advertisement mounted on foamcore	Wednesday, April 30th, 11:30-1:20
binder & envelope of sketches	Wednesday, April 30th, 11:30-1:20
Presentation!	Wednesday, April 30th, 11:30-1:20

Appendix D

Time Recording Sheet

Interior Design - Chair Project
Time Sheet

Name:

Date	Activity	Time Spent
	Note: possible list of activities includes, but is not limited to: Simple model construction, Detailed model construction, preliminary sketching, 2D CAD drawings, 3D CAD drawings, Discussing the project with others, Detailed hand drawings/ renderings.	

Appendix E

Cost Recording Sheet

Interior Design - Chair Project
Cost Sheet

Name:

Date	Activity	Cost
	Note: possible list of activities includes, but is not limited to: Simple model construction, Detailed model construction, preliminary sketching, 2D CAD drawings, 3D CAD drawings, Discussing the project with others, Detailed hand drawings/ renderings.	

Appendix F

Letter of Information

Memorandum

LETTER OF INFORMATION

To: All participating students
From: Paul Schreuders; Scott Greenhalgh
Date: April 7, 2008
Re: Research Survey

You must be 18 years of age or older to participate in this study

We are performing a research study to examine methods and effects of model construction in a classroom setting. There will be approximately 60 participants in this study.

Participating in this survey is considered minimal risk and your participation is voluntary. Participation in the experiment does not guarantee the availability of the rapid prototype machine, and participation is randomized into either a control or experimental group. Participation in the study will require you to fund your project as needed. You will be asked to describe your experience with the model construction exercise in a survey, as well as account for the time and money invested into the project. This information will be compared to the grade you receive on the model assignment, as filled out by your instructor as well as other instructors from within the Interior Design Department. Your participation in this study will only be for spring semester 2008. If you choose not to participate, you will not be penalized. If you begin the study and decide that you want to withdraw, all data pertaining to you will be removed from the research study.

While there is no direct benefit for you in participating, the results from this study may improve student success within the Interior Design Department. If you have any other questions or research related problems, you may reach Paul Schreuders at (435) 797-7559 or Scott Greenhalgh at (435) 590-7333.

To protect your privacy, you will be assigned a code number for use in all analyses and reporting of the data. Research records will be kept confidential, consistent with federal and state regulations. Paul Schreuders and Scott Greenhalgh will be the only researchers who have access to the data collected and it will be kept in a locked file cabinet. Personal, identifiable information will only be retained for 5 years.

The Institutional Review Board for the protection of human participants at USU has approved this research study. If you have any questions or concerns about your rights, you may contact them at (435) 797-1821.

Paul D. Schreuders, Ph.D.	4/7/08 Date	Scott D. Greenhalgh	4/7/08 Date

Appendix G

Interview Transcripts

Interview Transcript

Date: 3-25-08
Interviewer: Scott Greenhalgh
Interviewee: DeeAnne Olsen

Interview Observations

The interview was conducted in DeeAnne Olsen's Office in the Interior Design Offices. The interviewee seemed relaxed and at comfort with the interviewer. Body language seemed relaxed. The only difference from previous interactions was that in knowing this was an interview, and was recorded, so DeeAnne was more deliberate in word usage.

Note: "I:" denotes Responses by the interviewer; "D:" denotes responses by DeeAnne Olsen.

The Project

I: How would you describe the project, and how it has gone in the past? The processes within the project and the activities associated with it.

D: We start out studying ergonomics, anthropometrics, the scale of the human body, and, like we start out with the Vitrivuan Man by Leonardo, and human dimensions and averages and how different cultures and genders have different body measurements and start talking about ergonomics and adjustability and size, so they are starting to under stand a little bit.

And then they go around to several places on campus, and start to take measurements of the furniture, and start to putting a size to seat heights, arm heights, and seeing what is comfortable and maybe what is not comfortable, and a lot of the social aspects of how they feel in certain types of furniture.

Ant then they will start doing preliminary drawings. One thing that the project entails is that you do an ad which is going to marketable in a high end furniture magazine, and you would need to consider what the demographic would be. They will start with their prior experience with full scale models. They will then construct a final model which will be used in the advertisement, so the quality of the final model is important. All along they have to be conscious of different things- the construction, design, looks.

Experience with similar projects

I: And you have done that for how many years?

D: I have taught here for three years. Before that I taught at the high school and at Bridgerland Applied Technology College.

I: Do have any idea how long they have been doing that project here?

D: I don't know. Let me ask. (DeAnne then goes to the office next door to ask professor Darrin Brooks)

Close to twenty years.

I: Did you do similar projects at the high school and bridgerland?
D: At the high school we did models of houses, and at Bridgerland we did models of other things, but not furniture.

I: did you do a project like that in your undergraduate.
D: We had Milo Bachmann who is a real big furniture designer from back east, so we did a lot of models. And I actually did an internship with him so I had to build a lot of models, and he was very meticulous. He would have loved a rapid prototype machine.

Curriculum Impact
I: How would you expect the rapid prototype machine to impact the class curriculum?
D: I think it will help. When they first start designing, it's wide open, and they come up with some really clever designs, but when they start building a model and looking at how it is going to be constructed, they start to back off to designs with straight lines. So I think that the rapid prototype will increase the possibilities of the product design. I think it will open things up to what is possible to design.

I: Will it encourage students to challenge design?
D: I think that is one of the things that I am most excited for, is to see how they will challenge it- especially the ones that are not afraid of technology.

I: In the past, what were some of the negative things, the difficult things or the hurdles in the project?
D: The most difficult thing has been when they have these designs that they come up with do it building a model. They want it to look good, but they can't get it to work in a models. Their designs are good, but they can't build it.

I: How would you compare students graduating from a program with rapid prototyping versus students graduating from a program that does not incorporate that?
D: I think it does a lot for a student to go into a firm, especially a firm that does a lot with furniture, with rapid prototyping experience, and to realize what the machine does.

Demographic Impacts
I: How do you expect rapid prototyping to impact student of certain demographics? Things like age, gender, disposition for technology?
D: Age, I think is the biggest, the younger students are so used to technology, they are not afraid of it, not afraid of pushing it. I think they will grasp onto it. I don't know that if it is age or life experience, or if students are more craftsmen, or have a lot of experience with making furniture, they may be a little more hesitant to let go of that part of their design. It's like with manual drafting, some may feel that with technology it may become a lost art, but I think like with AutoCAD and other technology, you still have to understand the processes.

I: Do you think that it will impact other demographics? Like gender, or…

D: I think gender, with the technological side of it, and this is perception only, it seems to be more masculine, and so that men may be more attracted to that. Some may say, Oh, I didn't know that designers do that.

I: And how does the technology impact the female students?
D: Our students, I think it depends on how they came into the program. If they watched a lot of television shows like HGTV and were more interested in the decorating, I think the technology will be a little more frightening to think that they actually have to do this design. I think that design is fascinating because with design you have to incorporate the artistic portion, innovation, and construction. I think that when they realize that it seems like a lot.

I: So do you see a slight hesitancy and then acceptance?
D: It just depends on how the student came into the program. How much they know about the technology, and experience beforehand.

Impact on Program
I: And how do you expect the incorporation of rapid prototyping to impact the entire program?
D: Time is one thing. I know it will take time to get the students used to the technology, not just hey Scott, here's the plans and you make the machine work. Once students can learn how it works and what it can do. Overall, I think it is a great asset to the program.

I: what do you see as some of the limitations of rapid prototyping?
D: The only thing I think would be that maybe the students see the machine as magic, and they can cut corners off of design and the machine can build everything for them, and they won't be as diligent on the design, the scale, or the construction methods.

Interview Transcript

Date: 3-28-08
Interviewer: Scott Greenhalgh
Interviewee: Susan Tibbits

Interview Observations

The interview was conducted in Susan Tibbits' Office in the Interior Design Offices. The interviewee seemed relaxed and at comfort with the interviewer. Body language seemed relaxed.

Note: "I:" denotes Responses by the interviewer; "S:" denotes responses by Susan Tibbits.

The Project

I: How has the project gone in the past? What activities did you do what were the major parts of the project?
S: The way we started last year's , we started doing some inspiration, we did a critique, what design were going in what direction, and what wasn't and why. Just trying to teach them to be inventive and to use the inspiration. And then, did do, I think last year was the first time we did a preliminary model, just so we could test out any issues, you know the design issues that you want to work out before you put any money into it. Then the final came and then of course the ad.

Expected Impacts

I: What changes would you expect to occur with the implementation of rapid prototyping?
S: I hope that they will be better able to communicate their ideas. Because I know that they know what it looks like in their head, and to them it's perfect, and every time they try to build a model I doesn't come out right. Unless we have some fantastic model builders, which are few. And so, they will have some amazing ideas, and they literally don't show. They don't come off across as well as they need to. And we can go ahead and in our heads try to make the connections of what it should have been from what it actually looks like. I am hoping that this will take care of a lot of those issues, we'll have a lot better models, and more of them that look really good, and just communicate well.

I: In the past, what were some of the negative aspects of the project.
S: I think they have a hard time… It's kind of… It's a different project. Because it's just, it's not designing a whole space, it's just one thing, and you're putting everything you have into this one thing. So if you have a bad idea, and you carry it out, and your models bad and everything is bad, and you then have this horrible project that you wish would die. I don't know if there is really a way of changing that, but there may be a better result of this that makes them more pleased with their own work. That would probably one of the issues in the past. Those who don't build models well hate building models. They dread it. They have done their tiny house, and the next this is we ask them which they

built with foam core which they kind of understand now, now they are asked to deal with all these various materials that they don't know how to deal with, and they don't have a lot of time, and a lot of room for error. So, I think that is a part of the project that is complicated.

I: What would you expect to be the negative parts of the curriculum with the rapid prototyping?
S: I think it will just be interesting to see how they respond to it, the pressure is going to be that they have to be awesome at three D, and hopefully, there is always those that are, and they are going to be well prepared, and then there are going to be those who don't get it. They are going to have a hard time building it and getting it to be really what they want it to be. So that could be an issue, and I think just not understanding how it may work, and that could be taken care of by the demonstration of how it works. They tend to just feel overwhelmed. We ask them to do so much and then try to help them down the path, and they are like "you guys are crazy, we don't know what your doing" I hope it won't be like one of those type of experiences.

I: Are there any areas of the project that may require troubleshooting or making adjustments along the way?
S: I suspect that if we do a preliminary model, then later there will defiantly be design adjustments. I hope not after they build their models. If that does happen, then we'll find a way. If there are things that we need to switch out, but we have had to adjust models up until the end.

Demographic Impacts
I: how do you expect the rapid prototyping to affect the different groups of students? Like if we were to define students into a demographic, males or females, younger or older…
S: I don't know if there is going to be… its going to probably be those who feel comfortable with CAD, feel comfortable with their design skills, because they are more comfortable with those aspects, they will be more comfortable in taking a risk, and go out on a limb and try something new, more than someone who is not as confident with those other things. That's my guess of who will be more successful with this whole process.

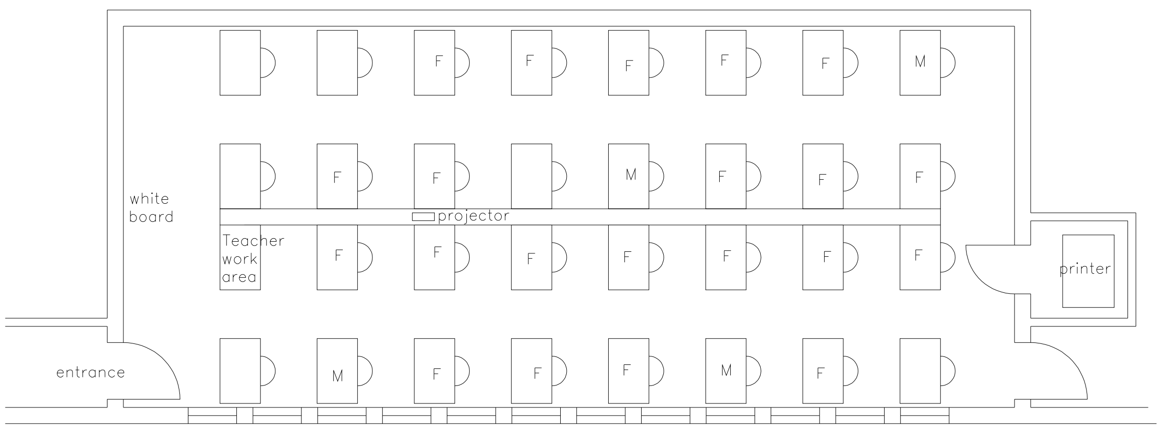
Design Impacts
I: Do you think that having rapid prototyping there will change students' designs? Do you think that they will try to push what the machine can do?
S: Thos who may lean toward the more contemporary or modern funky things may lean more towards the rapid prototyper. Yeah, I think there may be some who set out to use the rapid prototyper. I think some may be pumping us and say, ok, what do you think can be built on the rapid prototyper?

Program Impacts
I: how would you compare a student who graduates from a program that incorporates rapid prototyping versus a student who comes from a program who does not have any experience with it?
S: I don't know, we've had a few students do it, with the Karim Rasheed project, and I think that after we did that, and saw how well they turned out, and he was really encouraging students to move further with this, going back to the same ideas of being able to communicate your ideas effectively, and how important that is, and if you can get that knowledge down that you could move far past what you could have with a class. You can push the envelope further that you could have. It communicates their ideas so well. We are living without it, so we know what that is like, I think we see areas of potential in pursing our program further. I think we will see that result.

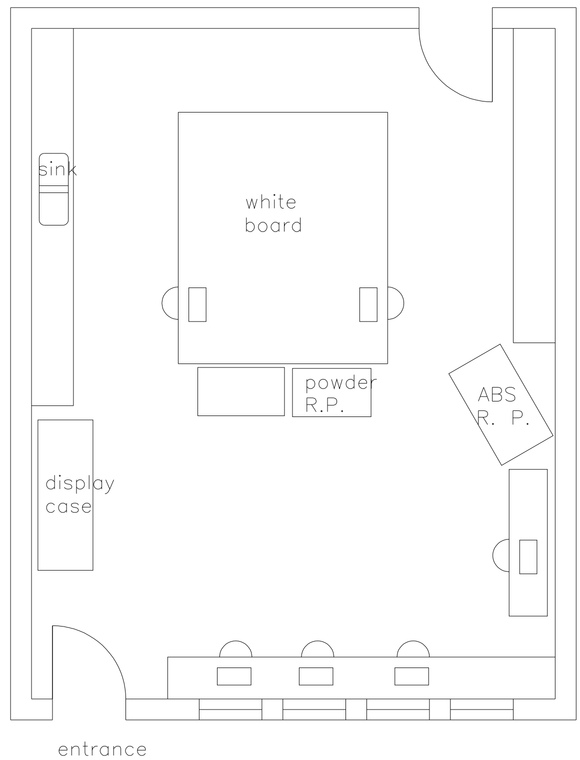
Appendix H

Observation Notes

Observation Notes:
Classroom setting:
The classroom is in a long building hidden behind the Family life building. For some reason, this small, one story building is known as the gun shed. There are two classrooms in this building with large windows to the west. The classroom is long and thin, about 25’x55’. The classroom is arranged with four columns of drafting tables extending eight rows back. For the Interior Design major, all students are required to own a laptop, so the students sat at the work tables with their laptops. A sketch of the classroom is provided below.



Rapid Prototyping Lab Setting:
The rapid prototyping lab is inside the Industrial Technology building and is housed near the center of the building. There are no exterior windows in the nearly square lab which is approximately 25’x30’. The lab is used by several instructors for several courses and purposes ranging from rapid prototyping, learning about small engines, biodiesel, and engineering concepts. A sketch of the lab is provided below.


sink
white
board
powder
R.P.
ABS
R. P.
display
case
entrance

Class: Space planning and Human Dimensions
Instructor: Deanne Olsen
Monday, April 7, 2008; 1:30 p.m.

I began my observation as the class had already begun. The students had been introduced to their assignment and were practicing design and sketching. The activity posed by the instructor was to draw from a theme or some sort of inspiration. The class consisted of four males and 21 females. The students were assigned to design around the theme android. The meaning was explained of the word was explained as being like C3PO from star wars. Robotic was given as a synonym. Several students moan like they don't like the theme, although one male student acts excited. He exclaims that he has an idea while the other students are either staring into space, staring at their sketch pads, and a few have begun to sketch. Slowly a few students start to sketch. Many spend the majority of their time staring off into space. After a few minutes, most students are now sketching. The instructor states that there are five minutes left to sketch. The students continue to sketch. Some finish sketching and wait for everyone else. Several students begin to talk to those sitting around them. The time expires before 1/3 of the students are done. The instructions are given to, like before, walk around and look at everyone else's sketches. They are given three starts that they can mark on designs they like. The students have clearly done this before and slowly get up and go around looking at the sketches. Four female students do not respond and do not participate and continue doing what they are doing. (I am unsure if this is with the assignment or something else). After the students make the rounds, the teacher calls on the students with the most stars to share and explain their designs to the class. The male student who seems so eager in everything volunteers in eagerness. Two other female students slowly join him, and one more is added after being prodded by her neighboring students. The students explain what their design is and what triggered their thoughts in those directions. About half of the class pays attention through eye contact while the other half seems disinterested. The teacher then brakes from the assignment to introduce the representative from the engineering and technology education department. The break in course tasks seems to regain the attention of some of the students. I introduce myself and my background in manufacturing and design and explains the department from which he comes. The question is posed, who here knows what rapid prototyping is? Only one student raises her hand. She tries to explain, but does not clearly state what it is. I go on to explain about 3D printing and layering techniques. The students do not seem to grasp the idea. The instructor continues to expound on the idea. After several minutes, there seems to be some understanding by some students. The announcement is given that it everyone will go for a field trip to see the machine in action. The students seem less responsive than anticipated. Everyone grabs their jacket, coat or what they have and begin walking to the other side of campus where the rapid prototype is located.

Everyone is shown the lab where the rapid prototype is located. Several examples are shown as to what the rapid prototype can do. The students crowd around the display case while the examples are shown. The interest level is much higher than during the initial demonstration. Students ask questions as to what material the machine can print.

How small of parts it can make and if they can make moving parts. The two rapid prototype machines are demonstrated to the students. The first is powder based. The Students show interest in how the technology and the machine work. The Students are then shown the plastic based printer. It is printing an object now, and the students take turns looking through the little window at what is being printed. Several students state that they think it is pretty cool how the technology works. The class is dismissed for the day. Six student stay after to ask questions about the machine and different ideas that they have. Afterwards, Deanne tells me that she thinks the students are really excited to use the machine.
Total time: approximately 30-40 minutes with fifteen minutes being used to walk from one building to another.

Class: Space planning and Human Dimensions
Instructor: Susan Tibbits
Tuesday April 8, 2008 4:20 p.m.

I started my observation similar to before, as class has been going for about an hour. The courses are set to follow the same activities and curriculum. The students were participating in the same activity as with the previous class. The students were designing according to a theme. The theme given for this class to design was a peacock. A picture of a male peacock was posted on the project to give the students a visual representation. The class consists of all females- about 22 of them. The students participated similar to the students in the previous class- seemingly slow to react to the activity. The students do as before in marking the designs they feel are best, and then sharing their direction and creation from the inspiration.

The teacher then breaks from the assignment to give me time to introduce the rapid prototyping part of the upcoming assignment. Like before, I introduce myself and my background in manufacturing and architecture. The question is then posed who knows what rapid prototyping is. Nobody responds. What about three dimensional printing? Nobody responds. I then explain how a three dimension computer model can be printed into a physical three dimensional object. After the explanation, it appears that the students do not understand. Another attempt is given to explain the process. The understanding of the process appears to be slightly understood, but in an abstract, science fiction sense. It appears that the students do not grasp the availability and application of the technology exists. To better understand the technology, the entire class then proceeds to go to the industrial science building.

The students are shown where the rapid prototyping machine is located. A quick run through of analyzing and preparing an object to print is given. The students pay attention but do not seem to be enthusiastic about this part of the process. The object is then printed. In the time it takes to warm up the printer, the students are show examples of printed parts. The students ask questions as to the colors which the machine can print and the materials that it prints. The interest peaks with the showing of the demonstration parts and the detail that can be printed. The plastic rapid prototyper begins to print by this time. Students can see how the printer begins to print. The students make comments on how they can see how it now works. The students are dismissed from class for the day. They fade away as most students stay until they have had a chance to examine and hold the printed parts and ask a few questions about the process. The interest level in the project seems to have increased tremendously after the display models are show to the student.

Total time: approximately 30-40 minutes with fifteen minutes being used to walk from one building to another.

Appendix I

Interview Protocol

Interview Protocol

The expectations and dispositions of the instructors prior to experience with rapid prototyping are desired in this study. The instructors will be interviewed after designing or revising their curriculum to include rapid prototyping, and before implementing the new curriculum.

The interviews will occur in a one-on-one setting in the instructors' offices to avoid distractions. A tape recorder will be present for later transactions. Additionally, the researcher will take notes during the interview.

Topic Domain: Why rapid prototyping?

Lead off Question: With your program and curriculum running smoothly, why do you want to change the curriculum to add rapid prototyping?

Covert Categories: Enthusiasm or resistance to technology; looking to technology to "fix" problems; disposition to technology; realistic expectations for rapid prototyping.

Possible follow up questions:

1. What positive changes will occur due to the curriculum changes?
2. What negative changes will occur due to the curriculum changes?
3. Do you expect student designs to change? How and or why?
4. Will the curriculum change improve the program? In what ways?
5. How would you compare students who graduate from a program with experience in rapid prototyping against students from a program without rapid prototyping experience?

Topic Domain: How does rapid prototyping affect students?

Lead off Question: How do you expect rapid prototyping to impact students?

Covert Categories: Looking to technology to "fix" problems; disposition to technology; expectations for rapid prototyping; addressing students as distinct individuals with distinct dispositions; addressing student holistically.

Possible follow up questions:

1. How will students react to using rapid prototyping?
2. Will all students react in a similar manner? If not, why?
3. How will rapid prototyping affect certain groups of students?
   Males?
   Females?
   White?
   Non-white?

Students with varying levels of technological background and dispositions?
Students with physical disabilities?
4. How will students perform comparatively between the two groups?

Topic Domain: Expectations being put into practice

Lead off Question: How do you expect the assignment to play out?

Covert Categories: Enthusiasm or resistance to technology; looking to technology to "fix" problems; disposition to technology; expectations for rapid prototyping; flexibility in curriculum; planning for program modifications; realistic expectations of technology.

Possible follow up questions:

6. Approximately how much time do you expect each phase to take?
7. What areas of the project will run smoothest?
8. What areas of the project may require troubleshooting or adjustments?
9. Is there a limit to the number of students that can reasonably use the rapid prototyping machine? What is that expected limit?

Appendix J

Individual Survey Question Results

Design Feedback

Table J-1

Percentage Responses to Question 2.1—The Following Tools have Influenced My Design Greatly:

Variable	Strongly agree	Agree	Disagree	Strongly disagree	Did not use
Preliminary sketches	57.9	42.1	0	0	0
Preliminary model	5.3	21.1	21.1	10.5	42.1
Final model	63.2	26.3	5.3	5.3	0
2D CAD drawing	31.6	15.8	0	0	52.6
3D CAD model	63.2	15.8	0	0	21.1
2D hand drawing	21.1	57.9	15.8	0	5.3
3D hand drawing	21.1	31.6	0	0	47.4

Table J-2

Percentage Responses to Question 2.2—The Following People have Influenced My Design Greatly:

Variable	Strongly agree	Agree	Disagree	Strongly disagree	Did not use
Instructor	21.1	68.4	5.3	5.3	0
Other instructors in ID	10.5	47.4	31.6	0	5.3
Students in class	31.6	42.1	10.5	0	10.5
Other students in ID	21.1	26.3	21.1	0	26.3
Students not in ID	0	36.8	26.3	5.3	26.3
Family	5.3	31.6	21.1	0	36.8
Other	0	0	0	0	100

Table J-3

Percentage Responses to Question 2.4—The Following Tools were Effective in Sharing Ideas:

Variable	Strongly agree	Agree	Disagree	Strongly disagree	Did not use
Preliminary sketches	63.2	31.6	0	5.3	0
Preliminary model	5.3	15.8	15.8	5.3	57.9
Final model	73.7	21.1	5.3	0	0
2D CAD drawing	15.8	15.8	5.3	10.5	47.4
3D CAD model	42.1	31.6	5.3	0	21.1
2D hand drawing	26.3	36.8	10.5	5.3	21.1
3D hand drawing	10.5	36.8	5.3	0	47.4

Table J-4

Percentage Responses to Question 2.5—Overall, I feel that the Quality of my Design has Improved Throughout the Project:

Response	Percent
Strongly agree	26.3
Agree	63.2
Disagree	5.3
Strongly disagree	5.3

Interest and Attitude

Table J-5

Percentage Responses to Question 3.1—I Enjoyed doing the Following:

Variable	Strongly agree	Agree	Disagree	Strongly disagree	Did not use
Preliminary sketches	42.1	42.1	15.8	0	0
Preliminary model	10.5	10.5	15.8	5.3	57.9
Final model	57.9	36.8	5.3	0	0
2D CAD drawing	15.8	15.8	10.5	10.5	47.4
3D CAD model	31.6	36.8	5.3	5.3	21.1
2D hand drawing	21.1	36.8	10.5	10.5	21.1
3D hand drawing	15.8	26.3	10.5	0	47.4

Table J-6

Percentage Responses to Question 3.2—I was Frustrated doing the Following:

Variable	Strongly agree	Agree	Disagree	Strongly disagree	Did not use
Preliminary sketches	0	15.8	63.2	15.8	0
Preliminary model	0	10.5	31.6	5.3	47.4
Final model	10.5	21.1	31.6	36.8	0
2D CAD drawing	0	10.5	26.3	21.1	36.8
3D CAD model	5.3	15.8	36.8	21.1	15.8
2D hand drawing	0	10.5	47.4	15.8	21.1
3D hand drawing	0	10.5	26.3	10.5	47.4

Table J-7

Percentage Responses to Question 3.3—As a student Learning About Design, I find the Following to be Valuable:

Variable	Strongly agree	Agree	Disagree	Strongly disagree
Preliminary sketches	78.9	21.1	0	0
Preliminary model	47.4	47.4	5.3	0
Final model	68.4	21.1	0	5.3
2D CAD drawing	36.8	57.9	0	5.3
3D CAD model	73.7	21.1	0	0
2D hand drawing	47.4	52.6	0	0
3D hand drawing	47.4	52.6	0	0

Table J-8

Percentage Responses to Question 3.4—If I were faced with a Similar Design Project as a Professional after Graduation, I would likely Create a:

Variable	Strongly agree	Agree	Disagree	Strongly disagree
Preliminary sketches	73.7	21.1	0	0
Preliminary model	42.1	42.1	10.5	0
Final model	78.9	15.8	0	0
2D CAD drawing	31.6	21.1	26.3	15.8
3D CAD model	78.9	21.1	0	0
2D hand drawing	42.1	26.3	10.5	10.5
3D hand drawing	42.1	10.5	26.3	15.8

Table J-9

Percentage Responses to Question 3.5—I Would Consider my Design Difficult to Build by Hand:

Response	Percent
Strongly agree	31.6
Agree	36.8
Disagree	31.6
Strongly disagree	0

Table J-10

Percentage Responses to Question 3.6—I Would Consider my Design Difficult to Build Using a Rapid Prototyping Technique:

Response	Percent
Strongly agree	10.5
Agree	26.3
Disagree	21.1
Strongly disagree	42.1

Table J-11

Percentage Responses to Question 3.7—The The Method of Construction Assigned to me (Hand Built or Rapid Prototyping) influenced my Design:

Response	Percent
Strongly agree	21.1
Agree	47.4
Disagree	26.3
Strongly disagree	5.3

Appendix K

Graphs of Enjoyment, Frustration, Professional Use, and Value

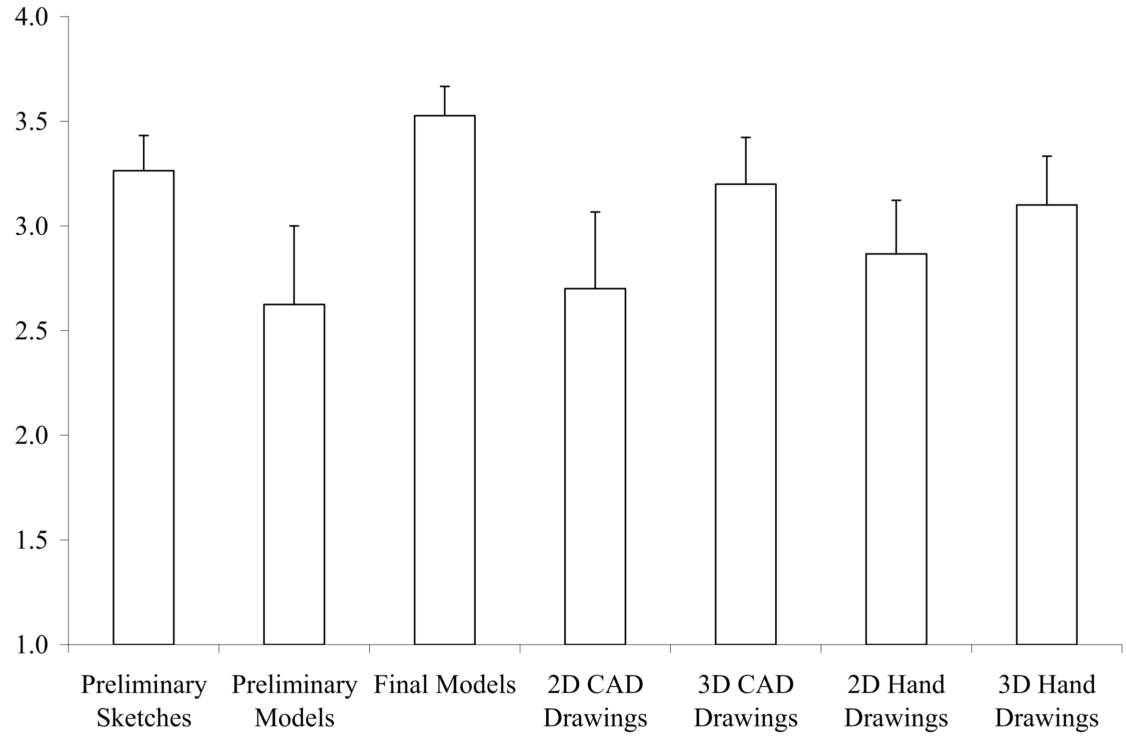


Figure K-1. Mean responses to the question: I enjoy doing the following: The graph show mean response to each source with the standard error of the mean being shown as whiskers above the plot. A value of one represents strongly disagreeing with the statement and a value of four represents strongly agreeing with the statement.

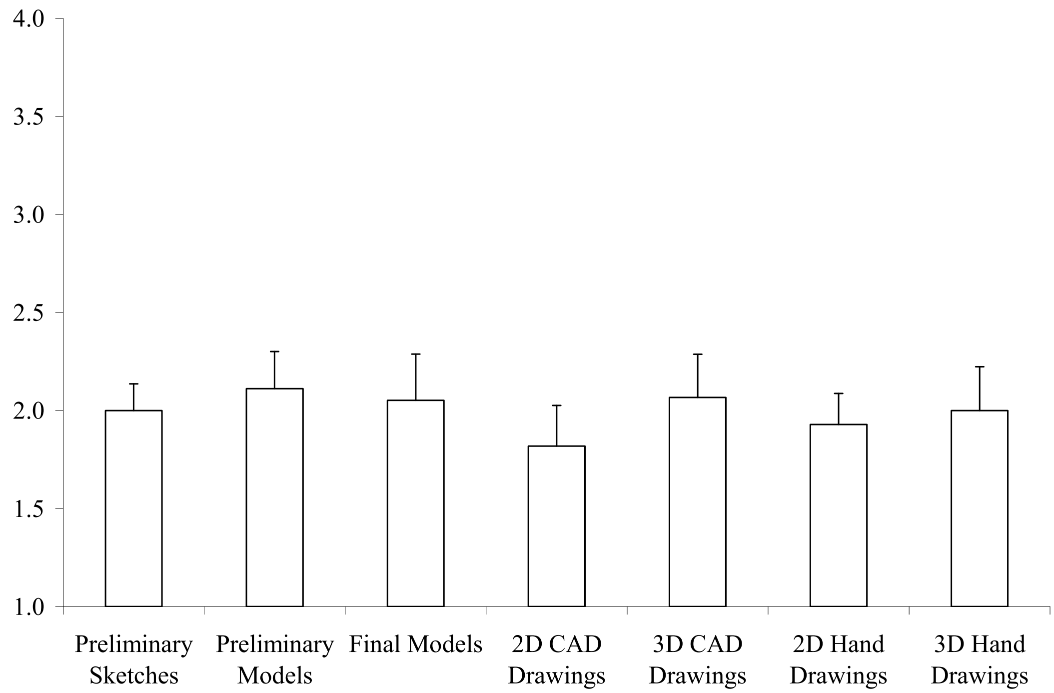


Figure K-2. Mean responses to the question: I was frustrated in doing the following: The graph show mean response to each source with the standard error of the mean being shown as whiskers above the plot. A value of one represents strongly disagreeing with the statement and a value of four represents strongly agreeing with the statement.

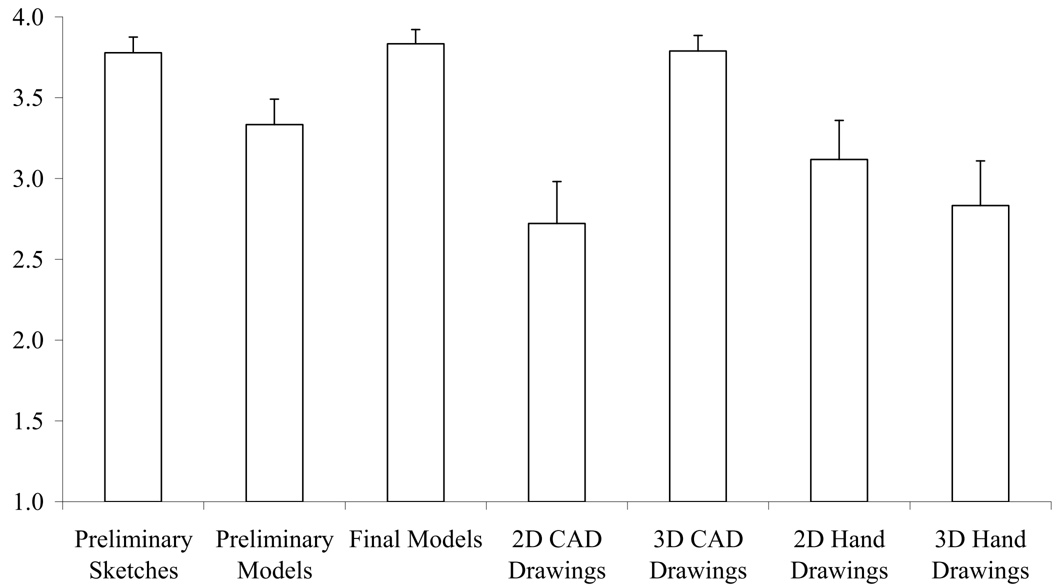


Figure K-3. Mean responses to the question: If I were faced with a similar design project as a professional after graduation, I would likely create a: The graph show mean response to each source with the standard error of the mean being shown as whiskers above the plot. A value of one represents strongly disagreeing with the statement and a value of four represents strongly agreeing with the statement.

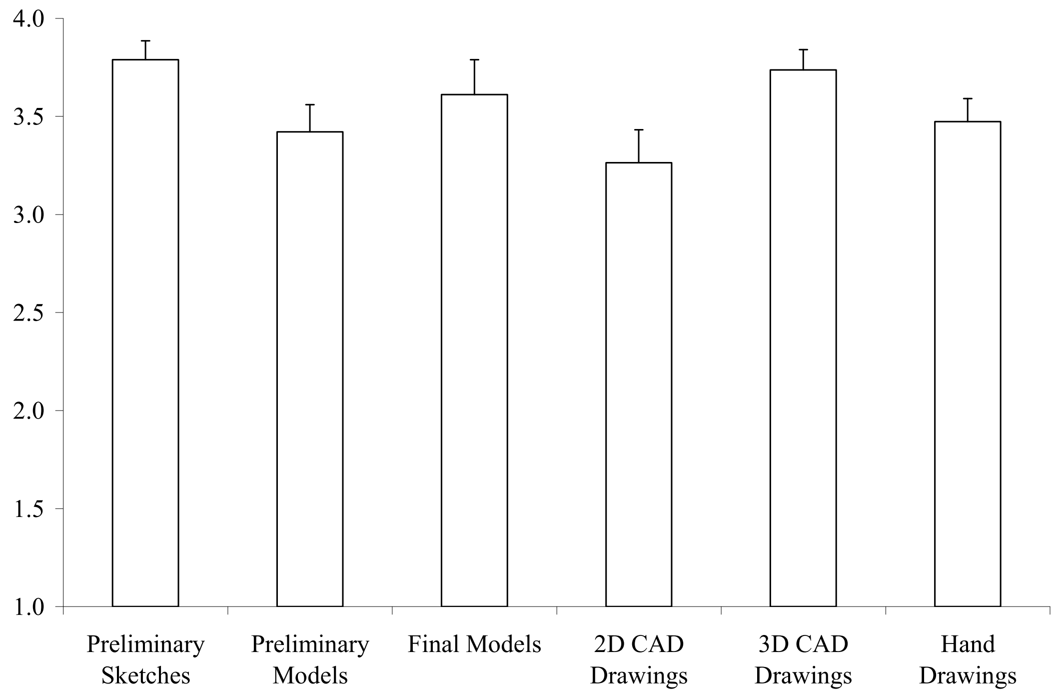


Figure K-4. Mean responses to the question: As a student learning about design, I find the following to be valuable: The graph show mean response to each source with the standard error of the mean being shown as whiskers above the plot. A value of one represents strongly disagreeing with the statement and a value of four represents strongly agreeing with the statement.

Appendix L

Coded Open-Ended Survey Responses

Question: What was the most positive aspect of creating a model?

Finished Model

Eight students identified finished models as being the most positive aspect of the project. The responses given by the students are reported in entirety in the open-ended response

1. Seeing a design go from sketches to an actual final product.
2. The finished product with the ad.
3. Seeing the final product.
4. Having the finished product done.
5. Seeing the finished product. I loved it!
6. The final result.
7. Being able to see the physical aspects of my design. It is one thing to see it on the computer screen, but to be able to see it and hold it brings it to life. I love it.
8. Being able to see my ideas become something real.

Design Process

The design process was identified by six students as being the most positive aspect of the project. Their responses are as follows:

1. I think the most positive part was watching the model actually take shape. From drawings to AutoCAD and then finally to the construction. It was really fun.
2. Working on it once the design and the methods of execution have been figured out.
3. It also allowed me to become more familiar with my model on a higher level.
4. To see the design go from concept on paper to a physical scaled object. Feels more like the whole design process.
5. Seeing a design go from sketches to an actual final product.
6. Drawing the sketches.

Ease of Assignment

Two students identified the ease of the assignment to be the most positive part of the assignment. One student used a rapid prototyping process, and one student used a hand construction process. The responses are given by the students as follows:

1. I was surprised at how easy it was. I was expecting the worst and found it wasn't that bad.
2. How easy my design was to build

Rapid Prototyping

Three Students identified rapid prototyping as being positive. The students state:

1. Rapid Prototype Machine worked great!
2. That the rapid prototype machine was able to put what was in my head into a physical form and it was very accurate
3. Being able to hand it over the prototyping process was the easiest part and I loved how it turned out. I was extremely pleased.

Knowledge

Two students identified learning as the best part of the assignment. The students make their claim:

1. It helped me to learn more about ergonomics and how things fit and work together.
2. Seeing the different machinery being used to build models.

Change of Pace

One student identified the change of pace as being positive. The student states: It was actually really fun, and I really enjoyed it because it was a nice change from the rest of the stuff we have done.

Question: What was the most negative part of creating a model?

Frustrations with Construction

Students identified frustrations as being the most negative part of the project. This was divided into frustrations with model construction, design, and CAD operations. Students state their frustrations with model construction:

1. It was a little frustrating building it by hand.
2. I guess the construction because I have no experience with working with metal and welding and stuff like that.

3. Gluing it all together.
4. Not knowing whether or not it would turn out looking good, which was before I used laser cutting.

Frustrations with CAD

Those students frustrated with CAD state their concerns:

1. Building the complicated twists and turns in CAD. It took much longer than I anticipated.
2. Building it in CAD took a lot longer than I had expected. I chose an organic shape, which was hard.
3. I had to rebuild my model in CAD twice.

Frustration With Design

Two students expressed frustration in the design process. They state their frustrations:

1. Making the design final.
2. I had to do a lot of trial and error to find out what exactly would work for the final model which can be frustrating.

Time and Cost

The investments of time and money into the project were considered by many students to be the most negative part of the assignment. Students who thought the project took more time and/ or money than they desired state:

1. Time.
2. The time used.
3. Building it in CAD took a lot longer than I had expected. I chose an organic shape which was hard.
4. Building the complicated twists and turns in CAD. It took much longer than I anticipated.
5. Cost most likely and the time required.
6. Too expensive.

Unavailability of Rapid Prototyping

Two students identified the random selection of students to be the most negative part of the assignment. They state their frustrations:

1. Not having the rapid prototyping create my chair to make it more accurate.
2. Not getting the rapid prototype machine.